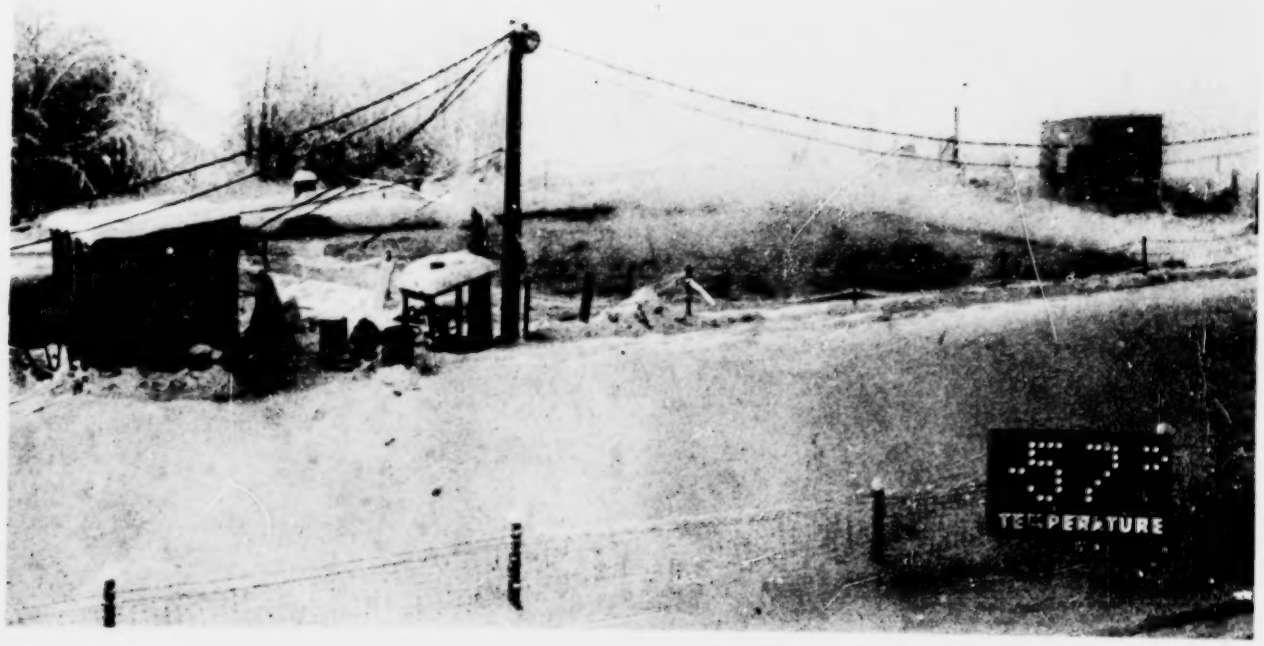
FEDERAL WATER QUALITY ADMINISTRATION
NORTHWEST REGION, ALASKA, WATER LABORATORY 1610 — — — 06/70

PB195673
W71-01262

BIOLOGICAL WASTE TREATMENT IN THE FAR NORTH



Reproduced by
NATIONAL TECHNICAL
INFORMATION SERVICE
Springfield, Va. 22151

JUNE 1970

1 Accession Number: W71-01262

2 Subject Field & Group: 05D, 5G, 10

SELECTED WATER RESOURCES ABSTRACTS
INPUT TRANSACTION FORM

5 Organization: Alaska Water Laboratory, Northwest Region, Federal Water Quality Administration, College, Alaska ~~99701~~

6 Title: Biological Waste Treatment in the Far North

10 Author(s):
Clark, Sidney E.
Coutts, Harold J.
Christianson, Conrad D.

16 Project Designation: FWQA-AWL 1610---06/70

21 Note: Available from the clearinghouse as PB 195 673, $3 in paper copy, 95¢ in microfiche

22 Citation: Federal Water Quality Administration Report, June 1970, 1610---06/70, 3 figures, 4 tables, 112 references, 26 pages.

23 Descriptors (Starred First): *Sewage treatment, *Biological treatment, *Sewage lagoons, *Activated sludge, *Oxidation ponds, Sewage disposal, Aerobic treatment, Stabilization ponds, Sewage disposal, Waste disposal, Waste water disposal, Waste treatment, Oxidation lagoons

25 Identifiers (Starred First): *Arctic sewage treatment, *Low temperature biological treatment, *Arctic sewage lagoons, *Low temperature activated sludge, *Cold regions extended aeration

27 Abstract:

A literature review to establish the state-of-the-art of biological waste treatment for cold regions applications was conducted. Comments were solicited from operating agencies throughout the cold regions of the Northern Hemisphere, particularly in the United States and Canada. These agencies have provided discussion of their experiences and offered their recommendations through letters and other forms of personal communications. The review centers on the feasibility for cold regions application of lagoons (aerated, facultative, and anaerobic) and extended aeration (12 to 36 hour detention activated sludge) with emphasis placed on the effectiveness of processes at low temperatures while treating domestic sewage. Although definite design criteria are not established, many of the recommendations and conclusions provide a better basis for cold regions design of biological waste treatment facilities. The limitations of existing knowledge are expressed and recommendations for continued research are presented. This report contains 112 references.

Abstractor: Sidney E. Clark

Institution: Alaska Water Laboratory

WR:102 (REV. JULY 1969)
WRSIC

SEND TO: WATER RESOURCES SCIENTIFIC INFORMATION CENTER
U.S. DEPARTMENT OF THE INTERIOR
WASHINGTON, D. C. 20240

* GPO: 1969—359-33

BIOLOGICAL WASTE TREATMENT

IN

THE FAR NORTH

by

Sidney E. Clark

Harold J. Coutts

Conrad Christianson

for the

FEDERAL WATER QUALITY ADMINISTRATION

DEPARTMENT OF THE INTERIOR

ALASKA WATER LABORATORY

COLLEGE, ALASKA

Project No. 1610----06/70

ABSTRACT

A literature review has been conducted to establish the published state-of-the-art of biological waste treatment for cold regions application. Operating agencies throughout the cold regions of the Northern Hemisphere, but particularly in the Northern United States and Canada, have provided discussion of their experience and have offered their recommendations through letters and other forms of personal communications. The review centers on the feasibility for cold regions application of lagoons (aerated, facultative, and anaerobic) and extended aeration (12 to 36 hour detention activated sludge) with emphasis placed on the effectiveness of processes at low temperatures while treating domestic sewage. Although definite design criteria are not established, many of the recommendations and conclusions should provide a better basis for cold regions design of biological waste treatment facilities. The limitations of existing knowledge are expressed and recommendations for continued research are presented.

Key Words: Arctic sewage treatment, low temperature biological treatment, biological waste treatment, waste treatment, sewage treatment, Arctic sewage lagoons, cold regions extended aeration, low temperature activated sludge.

CONTENTS

Section		Page
I	Summary	v
	Waste Stabilization Lagoons (Anaerobic and Facultative)	v
	Waste Stabilization Lagoons (Aerated Lagoons)	vi
	Activated Sludge	vii
II	Areas of Biological Waste Treatment Research and Development Needs	x
III	Introduction	1
IV	Waste Stabilization Lagoons	2
V	Activated Sludge	11
VI	Acknowledgements	18
VII	References	19
VIII	Appendix	28

FIGURES

		Page
1.	BOD Removal vs Detention Time AWL-Eielson AFB Aerated Lagoon Pilot Plant	29
2.	Sludge Samples Northway, Alaska, Aerated Lagoon June 1967	30
3.	Sludge Samples Northway, Alaska, Aerated Lagoon March 1970	31

TABLES

		Page
1.	Northern Regions Sewage Lagoon Performance Statistics	32
2.	Red Deer, Alberta, Sewage Lagoon System Characteristics	33
3.	Existing Lagoon Design Criteria (Facultative Lagoons)	34
4.	Sludge Bulking Hypotheses	35

SECTION I

SUMMARY

WASTE STABILIZATION LAGOONS (ANAEROBIC AND FACULTATIVE)

There are four important considerations in the design and use of anaerobic and facultative lagoons for waste treatment.

Public Health Implications: Anaerobic and facultative lagoons are a definite improvement over disposal to the street, back yards, or an outdoor privy. The application of these systems to waste disposal in remote villages, where a source of reasonably priced power supply is unavailable, should be given serious consideration. Bottom sludge definitely accumulates faster than it is stabilized, so the system will have to eventually be abandoned. The question then becomes one of, "How much public health hazard does an abandoned sewage lagoon create?" Deep lightly loaded lagoons will have many years of service. Information on the degree of winter removal of coliforms is extremely scarce; however, there does appear to be a significant reduction. Pathogenic organisms have been isolated from early expeditions and camps in the Antarctic and Arctic, indicating long survival under refrigerated conditions. (Alter, 6).

Nuisance Potential: Anaerobic and facultative lagoons should always be located downwind (prevailing) and at least one-quarter mile from the nearest inhabitants. An obvious and reasonably reliable means for minimizing odor production is the utilization of a design loading of 20 lbs. B.O.D. per acre per day or less. However, Alberta and the Northwest Territories have had reasonable success in minimizing odor production through utilization of deep primary cells loaded at high rates (1 to 4 day detention), followed by long detention time cells in series. The reasons why a short detention primary cell usually will not produce large amounts of odor are not clear. It is undoubtedly a combination of factors, two of which may be high flow rates in the overlying liquids, and the concentration of potential odor production in a small area.

System Loading and Process Efficiency Requirements: The evidence for utilizing anaerobic and facultative lagoon design loads of less than 50 lbs B.O.D. per day per acre is overwhelming. However, the favorable experience with several cells in series and utilization of a short detention time (1 to 4 days) deep primary cell is reasonably well documented, and should not be overlooked. Winter B.O.D. removal rates of 80-90 percent are not feasible, therefore, serious consideration must be given to winter storage with summer treatment in a shallow lagoon, where a two-cell system is feasible.

System Configuration and Construction: The influences of ice cover, frost-heave, and depth must be carefully considered in the physical design of lagoons for an extremely cold climate. Influent, cross-over, and effluent lines should be submerged, with the influent line centrally located. Canadian experience indicates that deep lagoons are preferable; however, the

question exists--What influence does the increase in depth have in the formation of a strong thermocline? Extreme care must be exercised in application of lagoons in permafrost areas, where ice-rich soil may exist.

WASTE STABILIZATION LAGOONS (AERATED LAGOONS)

Aerated lagoons have operated successfully in cold regions of the contiguous United States and Canada for a number of years. Aerated lagoons, as a process, have been reasonably successful in Alaska. The two main problems that occur with existing Alaska aerated lagoons are: (1) perforated tubing malfunction through clogging, and (2) embankment problems, including sloughing and frost-heave involving vertical walls. These problems are easily recognized and should be readily overcome. Aerated lagoons should definitely be given strong consideration for small population application.

Performance: B.O.D. removal efficiencies will vary with system detention time and summer or winter conditions. Winter removal rates will be higher than summer (summer algae population) by 5 to 10 percent. A system detention time of 15 days will provide treatment efficiencies greater than 80 percent, while a system detention time of 30 days--or twice the volume--provides increases in B.O.D. removal of 5 percent for summer and 10 percent for winter. The two-cell system should consist of a short detention (2-4 days) primary cell, followed by the secondary cell in series.

Air Requirements: O'Connor and Eckenfelder describe methods for predicting and calculating both the oxygen transfer and liquid velocity profiles for aerated lagoons, utilizing either point or line diffuser systems for air supply. Their design approaches are conservative for Alaska, because of its long winter, low temperatures, and extremely short periods of darkness during the summer.

Application of surface aerators is completely out of the question for most of Alaska. Both the fixed and floating units are extremely vulnerable to extensive icing.

Although the perforated plastic tubing has been utilized at a number of sites in Alaska, it has created extreme maintenance difficulties because of clogging and the resultant partial system failure. Most of the diffuser components developed for extended aeration package plants and activated sludge units can be readily applied to aerated lagoon design. Air pressure requirements must be held below 9 psi if inexpensive positive displacement compressors are going to provide extended reliable service. The aeration device should be so selected that the air pressure can easily be maintained below the compressor ratings if extended reliable service is to be provided. Design is the key engineering element necessary, not simply system selection from a catalog.

Because surface ice, four to five feet in depth may accumulate in the last one-half on a 30 day detention system in Alaska, deep lagoons should be utilized. Deep lagoons increase dissolved oxygen (D.O.) transfer, assist in mixing, and provide a more favorable system volume to surface area ratio to minimize heat losses.

Bottom Sludge Characteristics, Accumulation, and Digestion: Experience in Alaska has shown that from 1/2 inch to over 1 inch of sludge will accumulate per year during the first 5 years of operation. The above accumulation rates in a 30-day system works out from 1.5 to 4 cu. ft. per capita per year.

The bottom sludge receives very little, if any, biological degradation during the winter. During the summer, methane is produced during late July and August. The raw or partially treated sewage sludge first deposits near the influent of the plant. Summer anaerobic activity resuspends the sludge and it eventually levels out on the bottom, when a perforated tubing system provides the mixing.

ACTIVATED SLUDGE

Biological Activity and Temperature Effects: Successful operation of extended aeration plants at temperatures down to 2°C indicates that low temperature activated sludge treatment is feasible. The significance of temperature on the activated sludge process has been debated by many scientists with a wide spectrum of conclusions. Existing evidence reasonably supports the conclusion that temperature has little or no effect on the activated sludge process efficiency related to B.O.D. and solids removal at daily B.O.D. to Mixed Liquor Suspended Solids (MLSS) loadings of less than 0.5.

Temperature Coefficient: The temperature coefficient, has been evaluated by a number of investigators for low temperature activated sludge with values from 0.993 to 1.078. At daily loadings of less than 0.5 lbs. B.O.D. per lb. MLSS, it seems reasonable to conclude that the coefficient = 1.00.

Sludge Bulking: Extended aeration systems operating in the temperature range of 0°C to 8°C develop a bio-mass with very poor settling characteristics. The sludge volume index falls in the range of 150 to 300. A very high level of treatment can result, provided the solids separation and return system has the ability to cope with the situation. The sludge develops a very definite interface between clear liquid and sludge blanket during settling tests. Pipes (80, 81) has advanced a set of hypotheses to explain sludge bulking conditions and Heukelekian (54) has suggested some methods for "curing" a serious bulking problem once it has developed. The hypotheses and methods of cure must receive serious consideration as design factors. Activated sludges that have established a steady state condition at 0°C and 4°C seem to be stable at those temperatures, but are extremely prone to serious bulking as the liquid temperature rises to 8°C and above.

Temperature Influences On Solids Separation: The temperature influence on solids separation cannot be ignored if cold regions systems are to be designed with minimum environmental protection. A majority of the investigators working with low temperature activated sludge have pointed out the sensitivity of solids separation to temperature changes. It is not feasible at the present time to offer solids separation design criteria for activated sludge and extended aeration systems that will be operated for a significant period of time (2-3 weeks) below 5 to 8°C. Lightly

loaded existing systems have operated successfully when the liquid temperature was at 2°C. At the present time, a settling basin design overflow rate greater than 500 gpd/ft.^{2} appears to carry considerable risk of failure.

Upflow clarifiers and tube settlers appear to have considerable promise for low temperature operation. However, more investigation is necessary to establish acceptable loading rates, and to develop hardware and operation techniques that will guarantee continuous circulation of the active biological sludge through the settler. Stagnation and long residence times in the settler will allow the sludge to acquire poor settling characteristics and cause failure.

Solids separation systems actually located in the aeration basin have been utilized successfully and show great promise.

Aeration and Mixing: Mixing is an important consideration for extended aeration basin design. The bottom velocities must not be allowed to fall below one-half foot per second with one foot per second preferable. The oxidation ditch system that has been operated successfully in Alaska, allows sludge to settle out in the ditch, but this settled out sludge does not appear to adversely affect the performance. Periodic sludge release from a conservatively loaded settling basin does occur, especially during winter. Earthen basins with side slopes of 1 vertical to 2 horizontal or less may also be utilized in conjunction with a diffused air system. Basin turnover rates of once every 6 minutes or less and power supplies of 1/4 to one horsepower per 1000 feet of basin volume appear reasonable.

Preliminary observations suggest that an extremely cold air supply for a diffuser or brush system has both good and bad points: (1) ice fog production is reduced because water vapor transfer is minimized. (2) Additional air required to maintain an acceptable level of D.O. (approximately twice as much air at minus 60°F may be required as at plus 70°F). (3) An external heat source must be provided for compressors, especially when starting at cold temperatures.

Excess Sludge Disposal: More sludge wasting will be required when operating a 12-hour detention time system at less than 5°C than would be required at high temperature operation. More investigations are necessary before accurate predictions can be offered.

Alaska Package Plants: A number of package plants are in operation in Alaska. In general, the plants are poorly operated, are overloaded, and do not provide satisfactory levels of treatment.

If package plants are to provide satisfactory treatment, they must be properly designed, including adequate excess sludge storage; not be overloaded, and receive knowledgeable operation. Package plant suppliers should be required to provide service contracts for maintenance and operation supervision.

Environmental Protection: System size and raw sewage temperature are important considerations for cold regions process design and equipment selection. Small communities will show larger differences in raw sewage

temperature at the sewage treatment plant. Significant surface ice formation on an extended aeration basis cannot be tolerated because active biomass will be drawn out of the system into the ice and cause partial process failure. It seems reasonable to believe that facilities and communities of less than 300 contributing population will require environmental protection for the aeration basin if extended aeration is utilized. Communities of less than 1000 contributing population should not consider utilizing detention times greater than 24 hours with unprotected basins. Communities having populations greater than 1000 should have no difficulties in utilizing unprotected basins and detention times up to 48 hours and 72 hours for larger communities.

Unless the solids separation equipment is submerged within the aeration tank, because of its quiet surface, it will require environmental protection, regardless of community size.

Extented aeration package plants require environmental protection for several reasons; routine and emergency maintenance, mechanical equipment protection, and avoidance of surface ice.

Larger oxidation ditch systems do not require complete environmental protection, but do require protection over the brush.

temperature at the sewage treatment plant. Significant surface ice formation on an extended aeration basis cannot be tolerated because active biomass will be drawn out of the system into the ice and cause partial process failure. It seems reasonable to believe that facilities and communities of less than 300 contributing population will require environmental protection for the aeration basin if extended aeration is utilized. Communities of less than 1000 contributing population should not consider utilizing detention times greater than 24 hours with unprotected basins. Communities having populations greater than 1000 should have no difficulties in utilizing unprotected basins and detention times up to 48 hours and 72 hours for larger communities.

Unless the solids separation equipment is submerged within the aeration tank, because of its quiet surface, it will require environmental protection, regardless of community size.

Extented aeration package plants require environmental protection for several reasons; routine and emergency maintenance, mechanical equipment protection, and avoidance of surface ice.

Larger oxidation ditch systems do not require complete environmental protection, but do require protection over the brush.

SECTION II

AREAS OF BIOLOGICAL WASTE TREATMENT RESEARCH AND DEVELOPMENT NEEDS

Because the cold regions of North America represent a significant percentage of the total land mass, a better understanding of means for adapting existing treatment systems for cold regions application is necessary. The amount of work which has been done to extend our total knowledge to cold regions application (Arctic and Sub-Arctic) is insignificant in comparison to research and development work which provides reliable and effective treatment for the temperate climate. Little or no concern has been shown for protection of the Arctic and sub-Arctic from man's wastes until recently; therefore, very little capitalistic pressure has existed to create the necessary demand for Arctic and sub-Arctic waste disposal research and development. There are a number of treatment plant "monuments" scattered around Alaska to testify to our complete lack of ability to design systems that exist in harmony with natural forces, but instead must have adequate environmental protection to insure their reliability and integrity. The Arctic and sub-Arctic are going to develop, and the influx of people is going to be at exponential rates. Research and development must keep pace with the needs and hopefully gain a head start. Although this is not the subject of this report, a better understanding of the ecosystems into which waste treatment plant effluents are to be discharged is imperative to provide a basis for design requirements that are economically feasible. The following suggested areas of needed research are definitely only a partial listing that will be supplemented by other investigators.

Lagoons--Anaerobic and Facultative

*Anaerobic biological activity in bottom sludges at temperatures below 10°C.

*Application of a combination of winter storage--summer treated with a two-cell system, including a short detention (2-15 days) primary cell followed in series by a long detention time secondary cell (winter storage plus 30 days).

*Definition of ice behavior when operating in a winter storage mode with a large lagoon.

*Determination of total containment detention time requirements for winter storage to insure adequately treated discharge during periods of actual effluent discharge.

*Determination of long-term public health hazards created through bottom sludge accumulation at low temperatures.

*Investigation of methods of construction to minimize construction cost and insure reliability.

*Investigation of methods for provision of economical means for providing a leak-proof liner or surface preparation.

*Definition of influence of lagoon depth on bottom temperature profile over an annual cycle.

*Investigation of effectiveness of effluent disinfection, especially for winter discharge systems.

Lagoons - Aerated

*Survey of available diffuser components and investigation of their suitability and reliability for cold regions application.

*Determination of effectiveness of two cell system with short detention primary cell (1-5 days), followed by a secondary cell to provide total system detention time of 13 to 18 days.

*Determination of mixing capabilities of point and line source air diffusers operating under heavy ice cover in large lagoons.

*Investigation of feasibility of combination system, including 12 hour extended aeration system with integral solids separator, and the extended aeration system either contained within or at one end of a short detention time aerated lagoon (3-7 days).

*Investigation of methods and materials of construction including prefab systems to insure feasibility, economies of construction, and reliability, especially for small remote site applications, and locations with poor soil conditions.

*Investigate methods of excluding algae from summer effluents.

*Determination of long term public health hazards created through bottom sludge accumulation at low temperatures.

*Investigation of means for providing effective effluent disinfection, both summer and winter conditions.

*Quantitatively define optimum system detention time for maximum beneficial effects from algae.

Activated Sludge

Extended Aeration:

*Biokinetics determination and sludge characterization, both physical and microbiological for operation at temperatures below 8°C with various detention times.

*Define susceptibility of extended aeration systems to sludge bulking when subjected to temperature variations from 0 to 12°C (Particularily

cultures acclimatized at 0 to 4°C operation and then subjected to the temperature increase.)

*Develop design and operation criteria for low temperature horizontal flow clarifiers.

*Investigation of feasibility of earthen basin application including integral solids separation and return.

*Investigation of feasibility of upflow clarifiers and tube settlers including development of specialized operation schemes.

*Investigation of feasibility of iced-over clarifiers for unprotected winter outdoor operation.

*Investigation of materials of construction for stabilizing and sealing earthen basin systems.

*Definition of dissolved oxygen transfer rates at low air delivery temperatures (down to -70°F air) and determination of economics of heating intake air instead of provision of additional compressor capacity that probably is necessary for various detention time systems.

*Determination of power requirements and mixing characteristics for various earthen basin configurations.

*Determination and correlation of maximum allowable detention times for "Design" cold spells with environmentally unprotected systems relative to total daily influent heat energy (volume, surface area, and heat loss relationship), including correlation of total daily heat energy to projections of community size that will provide given heat energy levels.

*Investigation of hydraulics and system stability maintenance of solids concentration with heavy ice cover in which the flow patterns of mixing are parallel to the ice surface, such as the oxidation ditch.

*Effectiveness of low temperature disinfection of effluents from extended aerations systems.

*Investigation of nutrient removal capabilities at low temperatures, and development of modes of operation to optimize nutrient removal.

Standard Rate Activated Sludge:

*Biokinetics determination and sludge characterization for operating temperatures below 8°C and detention times of 3-8 hours.

*Definition of the susceptibility of various activated sludge processes to sludge bulking when subjected to temperature variations from 0 to 12°C.

*Development of design and operation criteria for low temperature and varying temperature horizontal flow clarifiers.

*Definition of dissolved oxygen transfer rates at low air delivery temperatures (down to -70°F air) and determination of economics of heating intake air verses provision of additional compressor capacity to compensate for lower transfer rates at extremely low air temperatures.

*Investigation of upflow clarifier and tube settler feasibility, including development of specialized operation schemes.

*Investigation of ice covered clarifier feasibility for unprotected winter outdoor operation.

*Determination of effectiveness of low temperature disinfection of effluents from various activated sludge processes.

*Determination of low temperature process nutrient removal capabilities, and modification of operation procedures to optimize nutrient removal capabilities of the systems, especially those operating for significant periods of time below 8°C.

*Investigate novel methods of solid separation such as a biological filter supported on a synthetic media (fiberglass cloth) as is done in the Chromaglass household plant (suggested by Edward Pohl).

Aerobic Sludge Digestion:

*Investigation of biokinetics of outdoor operation in conjunction with and as an integral part through physical location, not process mixing of activated sludge system (conservation of heat energy to maintain ice free system).

*Determination of air requirements for low temperature aerobic sludge digestion.

*Determination of low temperature influence on sludge concentration after digestion in aerobic system.

*Investigate freezing as a method of digested sludge concentration and dewatering.

Industrial Wastes

*State of the art determination for biological treatment of petrochemical wastes from refineries, fertilizer plants, etc., with specific emphasis on low temperature operation.

*State of the art and feasibility study for tertiary treatment of ballast water by biological polishing principals (including the possibility of utilizing a small portion of the estuary near a dock

operation as a treatment facility by creating a flexible membrane fence for the process).

SECTION III

INTRODUCTION

The dissolved oxygen concentration in the lower reaches of some Alaskan rivers may decrease to extremely low levels of 3 mg/l or less during winter periods of total ice cover (37, 42, 90). These conditions develop naturally and are not caused by man. The magnitude of these natural dissolved oxygen levels makes it essential that man's activities do not create intolerable conditions. It has been demonstrated that there is microbial activity at low temperatures (2, 9, 10, 11, 21, 26, 42, 44, 48, 64, 65, 73, 74, 75, 86, 88, 91, 92, 93, 95, 96, 111). The old myth that bacterial activity essentially ceases at low temperatures is incorrect and should be dismissed immediately. Waste treatment providing more removal than simple primary sedimentation will be necessary to protect the freshwater resources of the Far North as development brings increases in population.

Biological systems for providing secondary sewage treatment in temperate climates are well defined. However, little attention has been directed toward cold regions application of biological systems. This report is primarily concerned with interpretation of the available experience and is meant to assist in the design of these systems for cold regions application.

Background information for this report has been gathered through literature review, correspondence, and research in progress at the Alaska Water Laboratory.

SECTION IV

WASTE STABILIZATION LAGOONS

Since the first "engineered" waste stabilization lagoon in a northerly climate came into being at Fessenden, North Dakota, in 1928, considerable experience has accumulated. Many variations and loading schemes have been tried, tested and reported on.

Many names and adjectives have been used to describe waste stabilization lagoons and the various modifications. We suggest and will utilize the following definitions or constraints:

1. Anaerobic Lagoons--simple lagoons that receive wastes at loading rates high enough to exclude significant aerobic biological activity over an annual cycle.

2. Facultative Lagoons--simple lagoons receiving wastes at loading rates that allow significant aerobic biological activity during part or all of an annual cycle.

3. Aerated Lagoons--mechanically aerated lagoons having no provision for sludge separation and return.

Anaerobic and Facultative Lagoons

There are four very important aspects which must be considered in the utilization of anaerobic and facultative lagoons for waste treatment. When considering lagoons for Alaska and northern Canada application, strong emphasis must be placed on cold weather impact.

Public Health Implications: (Efficiency in destroying disease organisms, proximity to underground and surface water supplies, vector propagation). The Northern Regions Sewage Lagoon Performance Statistics presented in Table 1 indicate that efficiencies of removal of coliforms during cold weather operation are not well defined. Dawson (1,23,25) reports winter total coliform removals of 97.7-99.9+ percent at Inuvik and Yellowknife. The Northwest Territories villages of Inuvik and Yellowknife have natural shallow lakes which have been utilized as stabilization lagoons, and it is difficult to ascertain the contributions of the natural vegetation to the organic load.

The data presented in Table 1 and Table 2 indicate that bottom sludge will accumulate at a faster rate than it stabilizes. Generally, the farther north a site is, the higher the accumulation rate will be. This means that an anaerobic or facultative lagoon in Alaska will eventually have to be cleaned or abandoned. Apparent sludge accumulation at Fort Yukon, Alaska (21 lbs. B.O.D. per acre per day average loading for 15 years of operation equals 1 foot and represents 18 cubic feet per capita per year. However, several observed factors lead us to believe that actual sludge accumulation is more nearly 6 inches or less.

Sludge deposition in lagoons, located in areas where the lagoon bottom temperature remains low, concentrates sewage wastes and basically stores them for future correction. After abandonment, a potential health hazard may remain for an indefinite number of years. Pathogenic organisms have been isolated from the sewage deposits of early expeditions and camps in the Antarctic and Arctic many years after man's activities at the sites had ceased (Alter, 6).

Mosquito and fly breeding on existing vegetation in shallow natural lagoons or improperly cared-for embankments is and will definitely be a problem in northern application.

Nuisance Potential: (Proximity of habitation, existence of a properly identified lagoon enclosure, prevailing wind direction). If a lagoon is well maintained, fenced, and located downwind (prevailing winds) of inhabited locations, the odor problems can be minimized. Svore (103) found that loading rates are the key to odor control and states that design loading rates of 10 lbs. B.O.D. per acre per day usually eliminate spring breakup odor problems; 20 lbs. B.O.D. per acre per day creates odor which may persist for one to two weeks; 25-30 lbs. B.O.D. per acre per day creates odors for three to four weeks; and 50-60 lbs. B.O.D. per acre per day causes odors that persist for as long as three months. On the other hand, Brisbin (19), Dawson (23,24,25), and Higo (58) have found that odor control can be attained at much higher organic loading rates. Brisbin (19) stated that odors became such a serious problem in anaerobic cells, operating at 1080 lbs. B.O.D. per acre per day and detention times of 7 days, that they had to be bypassed at Moose Jaw, Saskatchewan. However, Sutherland, Saskatchewan lagoons, operating at loadings of 1300-2600 lbs. B.O.D. per acre per day and detention times of 2.75-1.45 days seldom created odors detectable at distances greater than 1000 feet; odors were generally only detectable at distances less than 100-300 feet. Dawson (Table 1) reports definite improvements at Yellowknife, Northwest Territories when a short detention anaerobic primary cell, having 0.6-day detention and 8-foot depth, was added. Higo (58) found that loading in terms of B.O.D. is not always a criterion for odor production. Innisfail and Red Deer, Alberta, with loadings of 3706 and 4708 lbs. B.O.D. per acre per day, did not experience odor problems, while Medicine Hat and Three Hills, Alberta, with loadings of 3910 and 4403 lbs. B.O.D. per acre per day, did experience odor problems. Odor problems were not experienced at Drayton Valley, Alberta, with 55.5 lbs. B.O.D. per acre per day loading or at Lacombe, Alberta, with 25.7 lbs. B.O.D. per acre per day loading, while odor problems definitely existed at Wetaskiwin, Alberta, with 248 lbs. B.O.D. per acre per day loading.

Odor production is obviously a function of the types of wastes discharged to a lagoon, but it is also a function of the organic loading, detention time, exposed surface area, location of influent line, depth, wind velocities, temperature and humidity. From the work of Higo (58), Dawson (23, 24, 25), and Brisbin (19), one might conclude that the potential for odor production can be minimized when designing short detention systems by provision of central submerged influents, depths of 10-20 feet, detentions of 2-4 days (not over 4 days at present flows), and B.O.D. loading not to exceed

9 lbs. B.O.D. per 100 feet^3 per day (4000 lbs. B.O.D. per acre per day at a 10-ft. depth).

System Loading and Process Efficiency Requirements: (Annual temperature, winter and summer monthly average temperatures, evaporation, precipitation, available sunlight, receiving water stipulations). Both anaerobic and facultative lagoons become anaerobic systems during winter ice cover and minimum sunlight conditions. Dawson and Grainge (23, 24, 25), (44) have found that stabilization lagoons operating under extreme winter conditions provide B.O.D. and solids removal rates that are approximately equivalent to primary waste treatment. Facultative and anaerobic lagoons rely heavily on bottom sludge decomposition for their long-term operation efficiency.

McCarty (69) considered the contribution of methane-producing bacteria to waste stabilization at temperatures below 12°C to be insignificant and that methane producers' activities become progressively less as the temperature decreases. Oswald (78) has shown that the quantity of gas production in the range of 5.5-10°C should be approximately 1/10 the rate for the same waste at 20°C. Without methane producing bacteria, bottom sludge decomposition is not carried to completion, organic acids build up, system pH is lowered, and bottom sludge decomposition becomes completely dependent upon liquid migration and diffusion to relieve the unfavorable pH condition. Coulter (21) found significant anaerobic activitiy at 4°C when conducting pilot studies with an anerobic contact process. The process had removal efficiencies of 55-78 percent for B.O.D. and 90-97 percent for suspended solids. Although this work indicated that a properly managed anaerobic system has potential for operating successfully at low temperatures, a contact system is completely different from a settled sludge layer in that the sludge layer does not have pH control. Upadhgay (106) conducted pure culture work with sugars to determine growth characteristics of psychrophilic anaerobes. Of 83 pure cultures, 28 strains, which formed both acid and gas, slowed considerably at the lower temperature. Ruble (91) analyzed samples from an experimental system near Fairbanks, Alaska, and found bottom sludge stabilization and 51 percent system B.O.D. reductions during the first winter's operation.

Both North Dakota (107) and Minnesota (4, 39) are recommending that stabilization lagoons be designed with sufficient volume to provide for retention of all winter flows; thus limiting effluent discharges to that period of the year when adequate treatment is obtained. The sewage should be retained long enough in the Spring for the wastes to be stabilized.

There are some interesting observations that can be made from the data in Tables 1 and 2. Winter B.O.D. and solids removal efficiencies are not significantly improved by longer detention times in a single cell, but are significantly improved when a system has several cells operated in series. Removal efficiencies do not appear to be affected by increases in lagoon depth. B.O.D. and solids removal efficiencies for

short detention time ponds, operated in series during the winter, seem to be sensitive to total system detention time, with an unstable zone for accumulative detention times of 6-10 days (Table 2). Bottom sludge can be expected to accumulate and the rate of accumulation will, in general, increase as one travels north. The rates observed by the Canadians vary from 8.75 to 14.0 feet^3 per 1000 people per day. Recent field information gathered at the Fort Yukon school indicates an accumulation of 1 foot of sludge in a lagoon of 0.51 acres operated since 1956 with average of 124 people per acre and a loading of 21 lbs. applied B.O.D. per acre per day. Chemical analysis of the sludge samples indicates that a significant portion of the loose "sludge" layer overlying the "bottom" actually has to be silt. Therefore, additional field studies are required to accurately determine actual sludge accumulation. A reasonable estimate appears to be 50 percent or less of the apparent sludge depth, or an actual depth of 6 inches or less and accumulation of 20 to 25 feet^3 per 1000 people per day. Ice cover on long detention time lagoons in Alberta, Canada, varies from 3.0-5.0 feet. Arctic lakes having large surface areas and depths greater than 7 feet are not expected to freeze solid.

As Oswald (79) pointed out, sunlight is an important consideration for summer design loading. Increases in north latitude provide longer days (sunrise to sunset) during the summer; therefore, the duration of solar energy available is greater. However, consideration must be given to the potential for shallow thermocline formation, which will reduce the depth of the aerobic zone. A pronounced thermocline will also reduce the potential for anaerobic decomposition during the summer. According to Oswald (77, 79), algae are capable of producing up to 200 lbs. of oxygen per acre per day with ideal temperature, illumination, and nutrients available. However, facultative lagoons do not provide ideal conditions. A pond of 4 ft. depth in the northern United States (excluding Alaska) has the ability to produce approximately 50 lbs. of oxygen per acre per day. With a design based on this information, one would be led to accept a loading factor of less than 50 lbs. B.O.D. per acre per day (Table 3).

System Configuration and Construction: (Depth, shape, number of cells, type and location of inlet, interconnection and outlet structure, acceptable levels of seepage, and sealant). The influences of ice cover and depth must be carefully considered in the physical design of lagoons for extremely cold climate. Influent lines should be submerged and centrally located in short detention time anaerobic lagoons, but must be protected from sludge plugging. Primary cell depths of 10-20 feet and minimum secondary cell depths of 8 feet plus 1 foot of freeboard should be provided (Dawson, 24). Sludge accumulation must be accomodated in the primary cells. The data in Table 1 indicate that it is reasonable to expect sludge accumulation rates of 13-14 ft.^{3} per 1000 persons per day.

Although Canadian experience and recommendations indicate deep cells, one must not overlook the possibilities that deep cells create the potential for strong thermoclines that may limit the bottom temperature more than shallow cells, where the thermoclines are less pronounced (if they exist at all). The Fort Yukon lagoon appears to be operating satisfactorily

with a winter depth of 8 feet. The system does not have an effluent and is located in a high groundwater area.

Construction techniques and system design must take winter problems into careful consideration. Frost-heave conditions will destroy a tight soil embankment with a steep slope. Improper location of the influent line will cause overflow conditions and related problems. The influent line should be submerged and centrally located, with an emergency inlet. Embankments should have a gravel core if possible, and a slope no greater than one vertical to three horizontal. Vertical walls may be ruptured by thermal expansion of ice.

Impermeable liners, such a polyvinyl chloride and low temperature butyl rubber, may not be economically competitive, considering the large system volume per capita involved. Exposed liners are impractical because ice movement will cause physical damage, regardless of degree of low temperature flexibility. Therefore, basic soil types must be given careful consideration to determine their suitability for lagoon application. Bentonite cannot be expected to seal highly porous soils such as sand and gravel. If the ground water system involved is of little or no value, quite possibly a leaky lagoon such as the one at Fort Yukon should be considered.

Extreme care must be taken when considering the application of lagoons in permafrost areas. Ice-rich soils (soils having 30-90 per cent ice content) provide a very poor foundation for systems that act as heat sources, providing energy to degrade the permafrost under them, with resultant subsidence.

Aerated Lagoons

Aerated lagoons have operated successfully in cold regions of the contiguous United States and Canada for a number of years. The first aerated lagoon in Alaska was located at the Eielson Air Force Base near Fairbanks and operated by the Arctic Health Research Center.

Performance: Reid (87, 88), operating the small lagoon located at the Eielson Air Force Base, reported B.O.D. removal efficiencies of 68-90 percent and suspended solids removal efficiencies of 67-68 percent for winter operation, with primary settled sewage loadings of 68-200 lbs. of B.O.D. per acre per day (0.4-3.1 lbs. B.O.D. per 1000 ft.^{3} per day). He found that loading rates between 0.4 and 2.4 lbs. B.O.D. per 1000 ft.^{3} per day gave efficiencies of 60-80 percent B.O.D. removal. The system was initially a single cell system with a depth of 4.4 ft. and a surface area of 0.31 acres; later this was changed to a two cell system. If we assume that all of the points on the curves presented by Reid (86) in November 1968, are for treatment of raw sewage, expected winter efficiencies should range between 58 percent at 6 days and 78 percent at 37 days. Respirometer studies were conducted at 0.5°C which yielded 65 percent removal for 5 days detention and 80 percent in less than 20 days.

McKinney (73) reported B.O.D. removal efficiencies of 88 percent at 9.3 days detention (1.4 lbs. B.O.D. per 1000 ft.^{3} per day) time with a water temperature of 3°C.

Kraft wastes from the pulp and paper industry were treated by Gellman (38) and B.O.D. removals of 56 percent at 2.5 days detention time, 70 percent after 5 days and 79 percent after 10 days at 2°C were obtained.

A 92.4 percent B.O.D. reduction with 40 days detention time in a 10 ft. deep aerated lagoon at Harvey, North Dakota, was reported by Olson (75).

Pohl (83) has shown that it should be completely feasible to obtain 90 percent B.O.D. reduction at 0.5°C in aerated lagoons operated at 10-15 days detention time.

Studies are currently being conducted on the aerated lagoon system located at Eielson Air Force Base. Although these studies are incomplete, one early summer and three winter efficiency curves are shown in Figure 1. These curves indicate that B.O.D. removals of 85 percent are attainable with 9 days detention time and 90 percent with 15 days detention time during the first winter's operation. Removals greater than 86 percent were not feasible and detention times greater than 18 days appeared to cause system efficiencies to decrease during the first early summer's operation. Late summer efficiencies appear to be lower.

The second winter performance curves show definite efficiency reductions compared to the first year winter curve. The January 1970 efficiency reduction compared to Winter 1969 curve, Figure 1, may be directly attributed to clogging of the perforated tubing diffuser system and resultant anaerobic conditions in the first two cells of the system. Cleaning with anhydrous hydrochloric acid gas was attempted several times. A new diffuser system has been placed in operation and initial results are represented in the February-March 1970 curve, Figure 1. Utilizing the same compressor, the new system greatly increased the mixing and a portion of the air supply is presently being by-passed to reduce the mixing for correlation with perforated tubing.

Two-cell aerated lagoon systems should be designed with a short detention time (2-4 days), first or primary cell, followed by a second cell or secondary cell that makes up the remainder of the system detention time.

Tests were conducted during the 1967 summer on an aerated lagoon located at Northway, Alaska, and it was found that the concentration of algae did not change with depth or location in the lagoon system. (The Northway lagoon is a two-cell system with 15 days detention time per cell at design, but presently has a total system of 50 to 60 days detention time). These findings indicated that preclusion of algae from an effluent will require a completely quiescent zone in the outfall area, and physical separation from the system circulation patterns is required.

Air Requirements: Aeration equipment has two purposes; namely, to maintain acceptable levels of dissolved oxygen (D.O.), and to provide system mixing.

O'connor and Eckenfelder (76) (Including discussion by Harold E. Orford) describe methods for predicting and calculating both the oxygen transfer and liquid velocity profiles for aerated lagoons utilizing either point or line diffuser sources of air supply. Their article should provide a basis of design that will be conservative under Alaska conditions. As O'Connor points out, relatively few aerated lagoons are complete mix systems with no sludge deposition. An absolute minimum bottom velocity of 1/2 ft. per second would be required at all locations in an aerated lagoon to actually have a complete mixing system, and a minimum of 1 ft per second would be preferable. McKinney and Benjes (72) describe the zone of complete mixing with mechanical aerators as that section which has a liquid velocity of at least 1 ft. per second. As the velocity falls, solids settle out and a condition of incomplete mixing prevails. There is no precise mathematical evaluation of incomplete mixing. Predictions of dissolved oxygen requirements must be empirical in nature.

The valve disc diffuser system presently being utilized at the Eielson facility was operated at 20 CFM for a 112,000 gallon system, with 12.1 ft. depth (10 ft. submergence), and has provided more than adquate oxygen transfer with 75 percent ice cover. Sludge is deposited in Alaska aerated lagoons throughout the year and receives little or no additional B.O.D. reduction during the long winter. Studies conducted at the Northway aerated lagoon indicate that bottom temperatures of 1/2°C may be expected during the months of November through mid-April. Bottom samples taken in April still show the deep green color of the past summer's algae population.

During the winter, D.O. requirements are less than theory would suggest, due in part to low anaerobic activity and at a time when the driving force for reoxygenation is highest. During the summer, bottom temperatures at Northway exceed 19°C allowing significant anaerobic activity with gas production to take place. The bottom sludge periodically re--enters the system through lifting, and undoubtedly a heavier B.O.D. load is imposed during the summer months. The long days of sunlight and twilight periods of Northern regions allow algae to produce oxygen more hours per day, thus reducing the actual D.O. requirements. Actually, the air supply for Northern regions aerated lagoons, treating domestic sewage is more a function of the desired degree of mixing and less one of supplying minimum D.O. requirements.

A well mixed culture of algae will produce a considerable quantity of oxygen when allowed to function at optimum temperature (15-25°C). According to Oswald (79), the production of D.O. by algae may be expected to drop rapidly as the temperature is decreased below 12°C. He found that approximately 10 percent as much D.O. was produced at 7°C as at 20°C. These observations make it obvious that reaeration must be provided through diffused air or surface mixing for a major portion of the year to assure aerobic conditions. Four fixed surface aerators and one floating aerator have been operating successfully in North Dakota. However, power curtailment allows the aerators to freeze up (107). A floating aerator has been observed operating without problems

at Hinton, Alberta, in a 4-day detention system when air temperatures were in the range of -25°F (Black, 13). However, the extreme winters in northern Canada and Alaska would make surface aerator operation very difficult because of heavy icing. A number of different types of diffusers do appear to be suitable for providing reaeration and mixing where surface aeration is not practical.

Since solids separation and return are not provided for in aerated lagoons, heavy activated sludge floc does not form. However, it seems reasonable to consider an aerated lagoon as a combination of aerobic digestion, flocculation, and sedimentation. On this basis, mixing requirements should be considered for maintaining an adequate zone of aerobic digestion above the sludge blanket, but allowing the heavier suspended sewage solids to settle out--not a complete mix system. An exception to this would be a short detention (1-3 days) primary cell, where most of the suspended solids should be maintained in suspension.

Although several different submerged aeration systems appear completely feasible for Alaska application, some of which have been utilized in Canada, only the performance of perforated plastic tubing manufactured by Hinde Engineering, Inc. has been reported in the literature. Reid (86) concluded that 20-40 ft. spacing of perforated tubing in the final one-third of an aerated lagoon would provide adequate mixing to assure a sufficient aerobic digestion zone. The results obtained by Reid, preliminary results of current Alaska Water Laboratory investigations, and aeration design approaches described by others (72, 76) indicate that air delivery and placement are not nearly as critical for aerated lagoons as for extended aeration and activated sludge. Although Reid (87, 88, 89) presented a strong case for the utilization of perforated tubing for aerated lagoons in cold regions, it is feasible to design other diffuser systems that will provide adequate mixing.

Current operating experience, utilizing perforated plastic tubing in a 12.1-ft-deep lagoon system, has required frequent repair and maintenance.

According to Van Heuvelen of North Dakota (107), "There are two waste treatment facilities of the diffused air tube type which have gone through several winters. The quality of effluent appeared to be satisfactory the first year, but operation and maintenance problems increased and the quality of the effluent decreased. The holes in the tubing were subject to clogging and the recommended cleaning method did not open them up. The compressors had to work under a higher pressure to overcome the additional back pressure caused by the holes being plugged. The additional maintenance caused considerable concern to the owners of these installations." In regard to cleaning procedures for the perforated plastic tubing diffuser systems, Stewart, City of Regina, Saskatchewan, (101) states, "The chief mechanical problem we have encountered is due to the small holes in the aeration tubing becoming blocked. It has been necessary to lower the water levels in the lagoons to clean the tubing holes, either by cutting new holes or by deforming (bending between two rollers). It appears in our case that deforming the tubing gave more lasting results."

The Eielson aerated lagoon air source consists of positive displacement compressors rated for continuous operation at 9 psi discharge pressure. When operated continuously at pressures above this level, they tend to become "unglued." It has been difficult to keep the operating pressure of the system at 9 psi or below, because of plugging of the tubing, even with frequent cleaning and replacement. The manufacturer's specified new tubing orifice drop of about 1 psi becomes over 3 psi in less than three months operation in the Eielson Air Force Base experimental aerated lagoon. With the valve disc diffuser system, as described earlier, operating pressures of less than 6 psi are easily maintained.

Bottom Sludge Characteristics, Accumulation, and Digestion: Reid (87) stated that sludge accumulation in the Eielson lagoon was at rates of 1/2 inch in the first quarter and 1/4 to 1/2 inch in the remaining three-fourths of the system.

The Northway aerated lagoon began operation in the Fall of 1965 with perforated tubing for aeration. In June 1967, sludge core samples were examined and appeared to be preserved exactly as deposited (See Figure 2). However, in August 1967 and May 1968, bottom samples had a definite black appearance and the physical characteristics of partially digested sludge. Significant methane production occurred during the summer of 1967. The maximum depth of bottom sludge did not increase, but its location shifted between the August 1967 and May 1968 sampling dates. This shifting seems to indicate that gas production resuspends bottom sludge and thus assists in providing aerobic and anaerobic digestion. The mixing action of aerated lagoons allows the sludge zone temperature to rise above 12°C during the months of June, July, August, and part of September in interior Alaska. Maximum bottom temperatures recorded at Northway were 19°C. Samples taken during March 1970 (Figure 3) at Northway indicate a sludge accumulation of approximately 6 inches in the first cell and approximately 3 inches in the second cell. The Northway lagoon started as a 30-day detention system but the detention time has gone up during the past 2 years, because of a population decrease from 68 in 1967 to 39 in 1970. In 4 1/2 years this indicates an accumulation rate of 1.0 inch per year, or approximately 9 $ft.^3$ per 1000 people per day. It is difficult to predict what the long range accumulation will be, as the long detention time aerated lagoon really is an eutrophic lake.

SECTION V

ACTIVATED SLUDGE

Many variations in the activated sludge process are possible and most of these are described by Stewart (102). Basically, activated sludge is a controlled symbiotic biological community in which bacteria, fungi, protozoans, etc., utilize sewage as food. The "control" is provided through shape and volume of the aeration tank, solids separation and return, intentional sludge wasting, and in some processes, sludge reaeration prior to returning it to the aeration basin. The determination of the ability of the activated sludge process to perform in cold regions is being studied. Temperature definitely does affect activated sludge, but the effect is not fully understood and probably is misinterpreted by many people.

Biological Activity and Temperature Effects: Evidence is available to indicate that considerable biological activity takes place at low temperatures. Halvorson (50) reported Devich (1948) as having observed an appreciable amount of enzyme activity at temperatures from -25°C upward. Ayres (10) made the following statement: "It is well known that bacterial growth can occur on frozen meat at -30°C and that yeasts and molds have been found to grow at as low as -7°C; also, on supercooled media, bacteria have been grown at -5°C and even at -7°C (Haines, 1937)." Wuhrmann (112), reporting on this studies of the activated sludge process, stated that "the B.O.D. removal seems to be only slightly influenced by temperature, whereas nitrification is markedly higher in summer than in winter." Ludzack (63) varied temperature and feed in studies of continuous activated sludge bench scale units. At 24 hours detention time and a loading of 35 lbs. C.O.D. per 1000 $ft.^3$ per day, he reported efficiencies greater than 90 percent at 21-25°C, 90 percent at 10°C, and 84 percent at 5°C. He believed that his low temperature units had not reached steady state. Hunter (61) conducted bench scale batch studies at temperatures between 4°C and 45°C and found little change in B.O.D. or suspended solids removal, but instead found a definite reduction of numbers of higher organisms and an increase in filamentous growth at the lower temperatures. Eckenfelder (26), in a discussion of temperature effects, stated, "Wuhrmann (private communication) and Eckenfelder (1966) have shown that at loading levels below approximately 0.5 lbs. B.O.D. per day per MLSS, (mixed liquor suspended solids), temperature has no effect on process performance." Goodman (41) evaluated a number of package plants and found no significant loss of B.O.D. removal efficiency when the liquid temperature was at 3-4°C.

Grube (46) evaluated an oxidation ditch (24 to 48 hour detention time) at College, Alaska, and found B.O.D. removal efficiencies greater than 90 percent with a liquid temperature of 2°C and air temperature of -40°C. Schmidtke (95, 96) concluded that the efficiency of an oxidation ditch was not noticeably influenced by low temperature. One of the ditches observed served Olds, Alberta. At a liquid temperature of 2°C and mixed

liquor concentrations of 2260-3400 mg/l (4530 mg/l maximum reported) B.O.D. removals of 85 percent were achieved.

Gustaffson (47) evaluated the activated sludge process for application at Kiruna, Sweden, and obtained 75 percent B.O.D. reduction with a 3 1/2 hour detention time system operation at 2700-3500 mg/l MLSS at 2.8-4.8°C.

Temperature Coefficient: The temperature coefficient, theta, $\theta\ k_1/k_2 = \theta\ [T_1-T_2]$), is utilized to define the effect of temperature changes on biological activity. Pohl (84) concluded that θ = 1.038 @ low MLSS and θ = 1.000 at high MLSS. Ludzack (64, 65) found that performance at different temperatures was dependent upon the nature of the feed. Cultures developed on soluble (primary effluent) feeds were more sensitive to temperature change than those developed on feeds containing suspended matter (effluent enriched with dog food). Benedict (11) conducted studies in the temperature range of 4-32°C and concluded that theta (θ = 1.078 @ 4°C) was independent of loading when the loading rate did not exceed 0.53 lbs. B.O.D. per day per lb. MLSS, but θ increased as loadings above 0.53 were imposed. Eckenfelder (29) suggested that θ, based on overall treatment efficiencies, was a function of the organic loading and reported the following values:

Activated sludge	θ = 1.00 @ low loadings θ = 1.02 @ high loadings
Aerated lagoons	θ = 1.06 - 1.08
Fair (32)	$\theta = 1.070 \pm 0.05$

The results obtained from bench scale activated sludge studies utilizing primary settled sewage conducted in the temperature range of 0.1°-8°C do not indicate that loading greatly influences the activated sludge process at low load factors (0 - 0.993 to 1.003; loading range of 0.10 to 0.30 lbs. B.O.D. per lb. per day. (MLSS).

Sludge Bulking: At low temperatures a very poor settling sludge develops, when operating in the 12-24 hour detention time range (F = 0.05 to 0.30 lbs. B.O.D. per day per lb. (MLSS). Work in progress at the Alaska Water Laboratory has demonstrated that a very effective treatment system providing B.O.D. removals consistently above 90 percent (primary effluent feed) can be developed in the temperature range of 0°C to 4°C. The system has a very poor settling sludge with sludge volume index (SVI) values of 200-240. When the system is returned gradually to a temperature of 8°C, the SVI goes above 240 and solids are lost out the effluent at very low overflow rates (360 gpd/ft.^{2}) gal. per day per ft.^{2}. Although very effective treatment is feasible with a "bulking" Sludge, the consistency with which this characteristic manifests itself under low temperature operation dictates that much clearer understanding of the "bulking" mechanism is necessary. Regardless of the potential effectiveness of a treatment system, if the solids separation system is incapable of retaining the biomass, a failure or partial failure will result. Microscopic examination of the activated sludge, both under "normal" operation and under

"bulking" conditions, does not suggest filamentous bulking conditions. The only really noticeable microscopic difference between 4°C "normal" sludge and 8°C "bulking" sludge is the reduction in numbers and activity of protozoans. The sludge moves from a reasonably granular matrix to a fluffy, snowflake appearance. Pipes (80) suggests that longer detention time systems (extended aeration, 12-24 hour detention time) are more prone to "bulking" as a result of conducting aerobic sludge digestion within the aeration basin and the condition might be reduced or eliminated by utilizing a shorter detention time aeration basins and providing for aerobic sludge digestion in a separate chamber. However, Downing (25A) shows that settleability is improved by longer detention (greater than 10 hours) and very short detention times (less than 5 hours) when operating an activated sludge plant at warm temperatures. The low temperature "bulking" condition appears to be a zoogleal condition as described by Heukelehian (54) and further discussed by Pipes (80, 81). Pipes (81) has advanced eighteen hypotheses for explanation and interpretation of bulking activated sludge (see listing in appendix). While work is in progress to define the bulking conditions and relate them to Professor Pipes' hypotheses, present understanding of the conditions, and their cure at low temperatures, is seriously lacking.

Temperature Influences Upon Solids Separation: Since the results which have been reported regarding the complex interaction of the physical, chemical, and biological characteristics of mixed liquor suspended solids separation are so diverse, it is no wonder that the influences of temperature have been largely ignored. The temperature influence cannot be ignored if cold regions systems are to be designed with minimum environmental protection. Reed (86), quoting others, stated, "Although activated sludge does not satisfy many of the assumptions of Stokes' Law, it is widely applied, and several investigators have noted the same velocity-viscosity relationship in studies of actual tanks...However, no general agreement is evident. Thomas...also cites studies by Ridenour and by Jenkins, et al, that did not appear to show any significant temperature effects." Pohl (84) found sludge settleability to be essentially unaffected by temperature changes in the range of 2-20°C. Ludzack (64) concluded that activated sludge flocculation was changed with temperature changes. Benedict (11) suggested that effects of sludge settleability on gross C.O.D. removal was magnified at low loadings and as loading rates were increased. His 4°C culture was a lighter color and produced a slightly turbid supernatant. Reed (86) found that the influence of temperature on settling velocity decreased as the concentration increased, with viscosity having complete control at very low concentrations and negligible effect at high concentrations. He also suggested upflow sludge blanket clarifiers as having greater potential for cold regions application.

Studies in progress at the Alaska Water Laboratory indicate that a low temperature culture (0.1° to 4°C) is slower to develop, but once developed produces a very clear effluent. The low temperature activated sludge does not produce a good settling floc. Early bench studies, utilizing Pope Scientific, Inc. cone reactors were encouraging, but too restrictive to determine some of the basic characteristics. Studies are currently under-

way utilizing two reactors, one with a pair of 2"x2"x48" steeply-inclined tube settlers and the second reactor with a pair of 2"x3-1/2"x72" tube settlers and a 4"x3-1/2"x72" tube settler. The studies with these plexiglass reactors indicate that upflow clarifiers will produce a very clear effluent, but means for returning the upper zone of the sludge blanket must be incorporated in the design. A biologically active sludge blanket cannot be considered in the same manner as a chemically coagulated floc blanket. The average residence time must be kept down, probably to less than 4 to 6 hours. During operation of the Alaska Water Laboratory tube settlers at 0°C liquid temperature, overflow rates greater than 0.7 gpm per ft.^{2} tube surface area (2"x2"x48" tubes @ 60° angle) make it impossible to maintain 4000 mg/l or greater mixed liquor suspended solids concentration. The sludge volume index (SVI) averaged greater than 200. At 4°C liquid temperature and 4000 mg/l MLSS concentration, an overflow rate of 0.8 gpm may be obtained prior to failure. However, when the system was brought up from 4°C gradually to 8°C and then allowed to "stabilize," the SVI's increased to greater than 250 and an overflow rate of 0.25 gpm/ft.^{2} caused failure when operating at 4000 mg/l MLSS.

Solid separation systems located in aeration basins show considerable promise. Rupke (92) found that several extended aeration systems in Ontario, utilizing clarifiers in the aeration zone, were not receiving adequate mixing and, therefore, a dispersed growth resulted with extremely poor settling. He infers that he believes the system would work with proper mining.

Design criteria must be developed that guarantees (1) adequate settler area to allow for efficient solids separation during the winter; (2) adequate protection against localized currents occurring within the settler module created by aeration basin turbulence; (3) adequate flow beneath the tubes to guarantee sludge removal; (4) protection from air entrainment within the tubes where tube settlers are utilized; (5) guaranteed sludge blanket renewal with a maximum residence time of 4 to 6 hours when upflow clarifiers are used including tube settlers, and (6) effective effluent drawoff.

Slechta (97) and Hansen (51) suggest surface loading rates for tube settlers of between 0.6 and 1.6 gpm/ft.^{2} with tubes 2 inches deep by 6 inches wide and 4 ft. long. Hansen (52) reports that a steeply inclined tube settler system located in the aeration tank of 3000 gpd prototype operated for more than 77 days in a temperate climate and provided treatment of secondary standards quite similar to the results obtained earlier with a conventional extended aeration package plant. The tubes were loaded at a 2 gpm/ft.^{2} overflow rate with 50 and 100 percent surges applied in the later part of the experiment.

Aeration and Mixing: The decision as to whether equipment design is controlled by mixing or aeration requirements is dictated by system loading and detention time.

Mixing: McKinney (72) stated, "The theory of complete mixing implies that all of the incoming wastewater components are adequately mixed with the

microbial mass and oxygen in the aeration unit. By practical criteria, the mixing should be complete in one minute. Liquid velocities of at least one foot per second are necessary." Complete mixing should be feasible with turbine aerators at 1/4 to 1/2 horsepower over 1000 ft.^{3} of aeration tank volume. Investigations carried out by Rupke (92) in Ontario demonstrate that mixing definitely controls extended aeration design. Existing systems having turnover times in the range of 12.4 minutes to 28.3 minutes were investigated and, in all cases, there was sludge deposition on the bottom. Aeration basin design turnover times less than 7 minutes are recommended.

Schmidtke (95, 96) reported on ditch-oriented modified brush aeration and stated that rotors operating at 100 rpm would transfer 1.6 lbs. O_2 per hour per ft. rotor length at 3 inch immersion and 7.61 lbs. O_2 per hour per ft. rotor length at 12 inch immersion. The power consumed in brush aeration varies as the 2.8th power of the brush speed, but directly as brush immersion. A 40,000 Imperial gallon 4-ft.-deep pilot plant utilizing a 27-1/2 inch diameter, 3 ft. long rotor with a constant speed of 85 rpm, was operated by Schmidtke. He reported that it was not difficult to maintain 1 mg/l D.O. and removal was 0.85 lbs. B.O.D. per kwhr @ 2.7 days detention and 1.55 lbs. B.O.D. per kwhr @ 1.1 days detention. B.O.D. removals during the summer exceeded 90 percent and averaged 85 percent during the winter. At Olds, Alberta, Schmidtke (95,96) noted that a brush operating with 9 inches submersion at 75 rpm was rated at 2.75 lbs. O_2 per hour per ft. of rotor with an average daily mean liquid velocity of 1.54 ft per second. Eddy currents just beyond the rotor, created by channel reduction at the rotor, caused embankment scour and the insides of the curves had sludge banks. Lipperverband (West Germany), as quoted by Schmidtke (95), showed that oxidation ditch depths up to 10 feet are feasible. Brush immersions of 8 cm and 16 cm were studied at a liquid temperature of 3°C

An oxidation ditch (24 hours detention time) with an unheated shelter over the rotor is located near Fairbanks. Raw sewage enters the plant at 7-8°C. Murphy (74) reported that this plant operates with a thin sheet of ice partially covering the ditch during extremely cold weather.

Diffused air systems are being investigated at the Eielson pilot plant for utilization in earthen basins. The results substantiate the commonly stated need for minimum bottom velocities of 0.5-1.0 ft. per second. Diffuser systems operated in basins without environmental protection appear quite feasible. The pilot plant at the Eielson Air Force Base, a 140,000-gallon plastic lined eartnen basin, has been operated without significant ice cover during a 25-day period with air temperatures of -40 to -50°C (influent sewage temperature 20-23°C, 1 to 2-day detentions). Preliminary observations suggest that an extremely cold air supply for a diffuser or brush system has both good and bad points: (1) more air is required to maintain a minimum D.O. level, (2) water vapor transfer is minimized, thus reducing ice fog production, and (3) care must be taken to provide an external source of heat for compressors and electric motors, especially when starting at cold temperatures.

Excess Sludge Disposal: The excess sludge that must be properly disposed of may be defined as net sludge accumulation Δx

$$\Delta x = a\ BOD_R - b\ (MLSS)$$

BOD_R = B. O. D. removed, lbs. per day

MLSS = Mixed Liquor suspended solids, lbs.

a = sludge yield coefficient, that fraction of B.O.D. removed that is converted to cellular mass.

b = endogenous metabolism coefficient, percent of MLSS cells destroyed by endogenous metabolims, percent per day.

Benedict (11) shows the following: that endogenous metabolism is temperature dependent and increases with temperature. The sludge yield coefficient a' (based on C.O.D. removal) also increases with temperature, and Δx is greater at 4° than at 19°C (b = 1.32 @ 4°C, b = 3.7 @ 19°C, a' = 0.42 @ 4°C, a' = 0.62 @ 19°C). His work strongly suggests that at lower temperatures a greater portion of the applied substrate is utilized for energy.

Alaska Package Plants: Most of the major manufacturers of package plants are represented among units in operation throughout Alaska, including a plant at Barrow, Alaska. Many of the plants are located at remote schools, Federal installations, etc. A majority of the package plants serve "islands" of development--housing developments, trailer courts, suburban schools, airports, Federal installations, and State facilities near population centers, namely Fairbanks and Anchorage. With only a couple of exceptions, the plants are housed or buried and heat provided. Benson (12) found that most of the plants were poorly operated and in a poor state of repair. He reports organics removal efficiencies ranging 11 to 76 percent, with solids removal of 78 to 89 percent. The major problems observed were overloaded settling basins, foam production, moisture problems, and equipment mechanical failure.

Knowledgeable operation is almost completely lacking. As sold by the manufacturer's sales representatives, they "operate" themselves. Many of the plants are overloaded and do not have excess sludge wasting, storage, or disposal programs.

If manufacturers are going to sell package plants in Alaska, they should be encouraged to set up service contracts to provide operations supervision and trouble-shooting, include excess sludge draw-off and storage capabilities, and increase the size of their settling basins. Eye (31) has found that a majority of the settling basins in package plants throughout the nation are improperly designed or undersized.

Environmental Protection: Environmental protection will be defined as the provision of housing, heating, etc. to protect equipment and processes from exposure to cold and wind. System size and raw sewage temperature are important considerations for cold regions process design and equipment

selection. Larger communities in interior Alaska (over 2500 population) may be expected to have minimum raw sewage temperatures of 4-6°C (Westgate and Arctic Park truck sewers, City of Fairbanks). The City of Fairbanks has minimum raw sewage temperatures at the plant of 9-11°C, yet has severe problems with small sewer lines freezing.

Extended aeration package plants require environmental protection for several reasons: routine and emergency maintenance, mechanical equipment protection, and avoidance of surface ice. Incoming sewage temperatures for small facilities can be expected to be near freezing. Immersion heaters have been utilized in the Anchorage area; however, maintenance and repair would dictate that interior and arctic Alaska package plants be completely housed.

Experience with the oxidation ditch operated by College Utilities indicates that an unheated protective housing for the brush is necessary, but housing for the ditch is not. An unheated insulated structure over a conventional buried sedimentation tank appears to be adequate.

Sewage and sludge pumps must be protected in heated enclosures. Positive displacement air compressors have been operated outside without environmental protection. Alaska Water Laboratory operations indicate that heated protection for the equipment is necessary, but provision of heated intake air is not. Equipment operated with -40° to -50°F exposure has a greatly increased incidence of failure. However, it might be cheaper to partially heat the air instead of providing additional air capacity for low temperature D.O. transfer when D.O. transfer rules design.

It is not necessary to provide housing and environmental control for extended aeration basins if adequate heat energy enters the system from raw sewage. Experiments conducted at the Eielson facility demonstrate that a maximum allowable detention time for extended aeration systems must be adopted for cold regions design. With an ice layer forming and growing over a well mixed aeration basin, the mixed liquor suspended solids concentration is easily reduced from 3500 mg/l down to less than 200 mg/l through entrainment of the solids in the forming ice. Such an active biomass removal cannot be tolerated; therefore, the maximum allowable detention time must be set according to heat energy needs and not completely on biokinetics. Small systems with a population equivalent of less than 200 appear to be ruled out for detention times greater than 24 hours, especially if the raw sewage temperature falls below 10°C. larger systems, such as Eielson Air Force Base (20°-23°C raw sewage temp) and the City of Fairbanks (10°-13°C raw sewage temp) are completely feasible for detention times up to 3 or 4 days.

Black (13) reported successful operation of a Welles floating aerator at Hinton, Alberta, and a Lightnin fixed unit at Prince George, British Columbia, in exposed temperatures of -29° to -35°C . Utilization of units that are dependent upon the surface staying clear of ice in their immediate area is extremely risky. While the surface or platform units may be acceptable for continuous operation at low air and water temperatures, repairs and maintenance become difficult and restarting the units becomes difficult or impossible, once iced.

SECTION VI

ACKNOWLEDGEMENTS

The insight and indepth knowledge held by the first Alaska Water Laboratory Director, Mr. Elroy K. Day, for Alaska needs provided the foundation on which the present research program is based, and from which this report represents the first in a series of cold regions waste treatment reports. His contribution is acknowledged with sincere thanks.

The able assistance and continuing advice of Mr. Amos J. Alter, Alaska Department of Health and Welfare, during the formulation of the Alaska Water Laboratory waste treatment research program and particularly during the various stages lending to this report is greatly appreciated and herein acknowledge with sincere thanks.

Dr. Edward C. Berry, Research Microbiologist, Alaska Water Laboratory, assisted in the development of low temperature activated sludge cultures and his advice and recommendations have provided a basis for further investigations represented in the present program. His contribution is acknowledged with sincere thanks.

SECTION VII

REFERENCES

1. Anonymous, "A Preliminary Report on Conventional Long-retention Sewage Lagoon Treatment at Inuvik, Northwest Territories," Dept. National Health and Welfare, Public Health Engineering Division, 541 Federal Public Bldg., Edmonton, Alberta, rough draft (January 6, 1966).

2. Anonymous, "Design and Operational Criteria for Aerated Lagoons in Alaska," Environmental Engineering Section, Arctic Health Research Laboratory, U.S. Public Health Service (June 1967).

3. Anonymous, "Observations on a Sewage Oxidation Pond in South Central Alaska," Technical Documentary Report AAL-TDR-64-17, Arctic Aeromedical Laboratory (January 1965).

4. Anonymous, "Sewage Stabilization Ponds in Minnesota," Minnesota Dept. Health, Division of Environmental Sanitation, Section of Water Pollution Control (March 1963).

5. Almgren, Howard, "Extended Aeration Research Project," Royal Norwegian Council for Scientific and Industrial Research and Norwegian Institute for Water Research (January 1969).

6. Alter, Amos J., "Sewerage and Sewage Disposal in Cold Regions," DA Project IT062112A130, Corps of Engineers, U.S. Army Cold Regions Research and Engineering Laboratory, Cold Regions Science and Engineering Monograph III-C56 (October 1969).

7. Anderegg, J. A., Walters, C.F., Hilliard, B., and Myers, H.F., "Eskimo Algae Make Lagoons Work at the Arctic Circle," reprint from Waste Engineering (June 1960).

8. Anderegg, J.A., Walters, C.F., Hilliard, B., and Myers, H.F., "Sewage Lagoons in Alaska," paper presented at the 10th Alaska Science Conference of the Alaska Division, American Association of for the Advancement of Science, Juneau, Alaska (August 27, 1959).

9. Atwell, James S., "The Effect of Temperature on the Activated Sludge System," :hesis, University of Maine (1967).

10. Ayres, John C., "Temperature and Moisture Requirements," Low Temperature Microbiology Symposium Proceedings (Camden), Campbell Sout Company (1962).

11. Benedict, Arthur Howe, "Organic Loading and Temperature in Bio-oxidation," Doctor of Philosophy thesis, University of Washington, (1968).

12. Benson, Barrett E., "Investigation of Existing Extended Aeration Waste Treatment Plants," Environmental Engineering Section, Arctic Health Research Center, U.S. Public Health Service.

13. Black, S.A., "Icing of Mechanical Aerators on Lagoons Under Cold Climate Operating Conditions," Division of Research, Onatrio Water Resources Commission, Bulletin RP-2018 (October 1968).

14. Black, S.A., "Phosphorus Reduction by Algal Cultures," Division of Research, Ontario Water Resources Commission, Bulletin No. 2004 (March 1967).

15. Black, S.A., "Review of Effluent Polishing Plant Study, Brampton-Chinguacousy, W.P.C.P." Division of Research, Ontario Water Resources Commission, Publication No. 13.

16. Bloodgood, Don E., "The Effect of Temperature and Organic Loading Upon Activated Sludge Plant Operation," paper presented at 17th annual meeting, Central States Sewage Works Association, Oshkosh, Wisconsin, June 22-24, 1944, Sewage Works Journal 16, No. 5, pp. 913-924.

17. Brink, C.W., "Operation and Maintenance of Sewage Lagoons," Water and Sewage Works (December 1961).

18. Brink, Claiborne W., Division of Environmental Sanitation, State Dept. of Health, State of Montana. Personal Communication (January 2, 1969).

19. Brisbin, K.J., Forsberg, C.R., McDonald, R.A., and McGrath, M.W., "Anaerobic Waste Stabilization Ponds," Water and Pollution Control (December 1967).

20. Christie, A.E., "Virus Reduction in the Waste Stabilization Pond," Division of Research, Ontario Water Resources Commission, Publication No. 9 (June 1966).

21. Coulter, J.B., Soneda, S., and Ettinger, M.B., "Anaerobic Contact Process for Sewage Disposal," Sewage and Industrial Wastes, 29, No. 12, pp. 468-477 (December 1957).

22. Culp, Gordon, "A Better Settling Basin," The American City (January 1969).

23. Dawson, R.N., "Lagoon Sewage Treatment in the Mackenzie District, Northwest Territories," Division of Public Health Engineering, Dept. National Health and Welfare, 541 Federal Public Bldg., Edmonton, Alberta, M.S. thesis 67-30 (July 20, 1967).

24. Dawson, Robert, and Grainge, John W., "Proposed Design Criteria for Wastewater Lagoons in Arctic and sub-Arctic Regions," Journal Water Pollution Control Federation, pp. 237-246 (February 1969).

25. Dawson, R.N., "Sewage Lagoon Treatment, Yellowknife, Northwest Territories," Dept. National Health and Welfare, Public Health Engineering Division, 541 Federal Public Building, Edmonton, Alberta (June 17, 1966).

25A. Downing, A.L., "Factors to be Considered in the Design of Activated Sludge Plants," Advances in Water Quality Improvement, pp. 190-202, University of Texas Press (1968).

26. Eckenfelder, Wesley, Jr., "An Integration of Biological Waste Treatment Design," Environmental Health Engineering, University of Texas, Austin, Texas.

27. Eckenfelder, Wesley, Jr., Dept. of Civil Engineering, University of Texas, Austin, Texas, private communications (March 13, 1967).

28. Eckenfelder, Wesley, Jr., "Factors Affecting the Aeration Efficiency of Sewage and Industrial Wastes," Sewage and Industrial Wastes, 31 Federation of Sewage and Industrial Wastes Association (January-December 1959).

29. Eckenfelder, Wesley, Jr., "Theory of Biological Treatment of Trade Wastes," Journal Water Pollution Control Federation, 39, No. 240 (1967).

30. Eckenfelder, Wesley, Jr., and Ford, Davis L., "New Concepts in Oxygen Transfer and Aeration," Advances in Water Quality Improvement, Water Resources Symposium I, University of Texas Press (1968).

31. Eye, J. David, Eastwood, David P., Requena, Fernando, and Spath, David P., "Field Evaluation of the Performance of Extended Aeration Plants," Journal Water Pollution Control Federation, 41, No. 7, pp. 1299-1318 (July 1969).

32. Fair, Gordon M., Geyer, John Charles, and Okum, Daniel Alexander, Water and Wastewater Engineering, Vol. 2, Water Purification and Wastewater Treatment and Disposal, John Wiley & Sons, Inc. (1968).

33. Fisher, C.P., and Gloyna, E.F., "Stabilization Ponds," Journal of Water Pollution Control Federation, 37. No. 11, pp 1511-1520 (November 1965).

34. Fisher, Charles P., Drynan, W.R., and Van Fleet, G.L., "Waste Stabilization Pond Practices in Canada," Advances in Water Quality Improvement, University of Texas Press.

35. Forsberg, C.R., Prosko, M.D., Sentis, V.J., and Strilchuk, S.S., "Aerobic and Anaerobic Waste Stabilization Ponds," Civil Engineering Report, University of Saskatchewan.

36. Forsberg, C.R., "Tables - Typical Aerobic and Anaerobic Pond Results," Dept. of Civil Engineering, University of Saskatchewan (February 1968).

37. Frey, Paul, "Significance of Winter Dissolved Oxygen in Alaska," presented at the Alaska Water Management Association Annual Meeting, (May 1969).

38. Gellman, Isiah, and Burger, Herbert F., "Waste Stabilization Pond Practices in the Pulp and Paper Industry," Advances in Water Quality Improvement, University of Texas Press.

39. Ginner, Gary F., Section of Sewage Works, Pollution Control Agency, State of Minnesota, Minneapolis, Minnesota, personal communications (May 27, 1969).

40. Gloyna, Ernest F., "Basis for Waste Stabilization Pond Designs," Advances in Water Quality Improvement, Water Resources Symposium I, University of Texas Press (1968).

41. Goodman, Brian L., "Packaged Sewage Treatment Plants Criteria Development, Part I: Extended Aeration," National Sanitation Foundation, Ann Arbor, Michigan (September 1966).

42. Gordon, Ronald C., Research Microbiologist, Alaska Water Laboratory, College, Alaska. Unpublished data (April 1970).

43. Gotaas, Harold B., "Effect of Temperature on Oxidation of Sewage," Journal Federation of Sewage Works Association (1948).

44. Grainge, J.W. Public Health Engineering Division, Dept. National Health and Welfare, Edmonton, Alberta, private communication (March 10, 1967).

45. Green, David P., "Sewage Lagoons in the Rocky Mountains," paper presented at the Rocky Mountain Association of Milk and Food Sanitarians, Sanitation Section of the Western Branch of American Public Health Association.

46. Grube, Gareth Alden, "Evaluation of an Oxidation Ditch Activated Sludge Plant in sub-Arctic Alaska," M.S. thesis, University of Alaska, College, Alaska (May 1968).

47. Gustafsson, Bengt, and Westberg, Nils, "Experiments with Treatment of Sewage From the Town of Kisuan by the Activated Sludge Method," Royal Institute of Technology, Stockholm, Sewden, Institute of Water Supply and Sewerage Technology, Institute of Water Chemistry 65, No. 4 (1965).

48. Halvorson, Harvest, "Microbiology of Domestic Wastes, No. 2: A Comparative Study of the Seasonal Physiological Activity of Bacteria Indigenous to Sewage Lagoon," Canadian Journal of Microbiology, 15, No. 6 (1969).

49. Halvorson, Harvest, "Physiological Activity of Bacteria Indigenous to Lagoon Operation as a Function of Seasonal Change," Canadian Journal of Microbiology, 14, No. 4 (April 1968).

50. Halvorson, H.O., "Initiation of Growth at Low Temperatures," Low Temperature Microbiology Symposium Proceedings (Camden), Campbell Soup Company (1962).

51. Hansen, Sigurd P., Senior Application Engineer, Neptune Microfloc, Inc., Corvallis, Oregon, personal communications (September 8, 1969).

52. Hansen, Sigurd P., Culp, Gordon L., and Stukenberg, John R., "Practical Application of Idealized Sedimentation Theory in Waste water Treatment," Journal of Water Pollution Control Federation, 41, No. 8, Part P, pp 1421-1444 (August 1969).

53. Hermann, E.R. and Gloyna, "Waste Stabilization Ponds, Part III: Formulation of Design Equations," Report No. 47, Sewage and Industrial Wastes, University of Texas, Bureau of Engineering Research (August 1958).

54. Heukelekian, H., and Weisberg, E., "Bound Water and Activated Sludge Bulking," Sewage and Industrial Wastes, 28, No. 4, p. 558 (April 1956).

55. Higgins, P.M., "The Engineering Behind Waste Stabilization Lagoons," Seminar of the Canadian Society of Microbiologists, Manitoba Branch (December 2, 1965).

56. Higgins, P.M.,"Problems and New Developments in Lagooning of Wastes," presented at the Canadian Institute of Public Health Inspectors, Dominion Conference, Winnipeg, Manitoba (July 13, 1965).

57. Higgins, P.M., "Waste Stabilization Ponds--Health Hazard or Effective Treatment Device?" rebuttal to 1964 issue of Canadian Medical Assoc. Journal, carrying sleepy lagoon story, Canadian Municipal Utilities, pp. 35-37 (February 1965).

58. Higo, T.T., "A Study of the Operation of Sewage Ponds in the Province of Alberta," Division of Sanitary Engineering Dept., Public Health, Government of Alberta, Edmonton, Alberta (March 1965).

59. Hopwood, A.P., and Downing, A.L., "Factors Affecting the Rate of Production and Properties of Activated Sludge in Plants Treating Domestic Sewage," Journal of the Institute of Sewage Purification (1965).

60. Horning, William H., II, Porges, Ralph, Clark, Harold F., and Cook, William Bridge, "Waste Stabilization Pond Study, Lebanon, Ohio," Environmental Health Series, Water Supply and Pollution Control, U.S. Dept. Health, Education and Welfare, Public Health Service (May 1964).

61. Hunter, T.V., Genetelli, E.J., and Gilwood, M.E., "Temperature and Retention Time Relationships in the Activated Sludge Process," Proceedings of 21st Industrial Waste Conference, Purdue University, 953 (1966).

62. Karl, Charles E., "Waste Treatment by Stabilization Ponds," presented at the 47th annual meeting of the International Association of Milk and Food Sanitarians, Inc., Chicago, Illinois (October 26-29, 1960).

63. Ludzack, F.J., "Observations on Bench Scale Extended Aeration Sewage Treatment," Journal Water Pollution Control Federation, 3, No. 8, pp 1092-1100 (August 1965).

64. Ludzak, F.J., and Cairns, Jay, Jr., "Temperature and Feed as Variables in Activated Sludge Performance," The Effects of Increased Temperature on Aquatic Organisms, proceedings of 10th Industrial Waste Conference, Purdue University Extension Serv., 89, p 346 (1956).

65. Ludzack, F.J., Chemist, FWQA Training Activities, Cincinnati, Ohio, private communications.

66. Kay, L.A., Chief Engineer, Environmental Sanitation, Dept. Health, Province of Manitoba, Winnipeg, Manitoba, private communications (April 27, 1967).

67. Macdonald, R.W., Chief Engineer, Water Improvement Commission, State of Maine, Agusta, Maine, private communications (March 15, 1967).

68. Mancini, John L., and Barnhart, Edwin I., "Industrial Waste Treatment in Aerated Lagoons," Advances in Water Quality Improvement, Water Resources Symposium I, University of Texas Press (1968).

69. McCarty, Perry, Professor, Dept. of Civil Engineering, Stanford University, Palo Alto, California, personal communication (May 1967).

70. McDonald, Norman G., "Activated Sludge Treatment at Edmonton, Alberta," Sewage and Industrial Wastes, 31, No. 8, pp 909-922 (August 1959).

71. McDonald, R.A., "Operational and Model Stabilization Ponds," M.S. thesis University of Saskatchewan (May 1966).

72. McKinney, Ross E., and Benjes, Henry H., Jr., "Design and Operation of Aerated Lagoons," Paper No. 3P2-1, National Symposium on Sanitary Engineering Research and Development and Design, Division of Sanitary Engineering, American Society Civil Engineers (July 27-30, 1965).

73. McKinney, Ross E., and Edde, Howard, "Aerated Lagoon for Suburban Sewage Disposal," Journal Water Pollution Control Federation, 33, No. 12, pp 1277-1285 (December 1961).

74. Murphy, R. Sage, Director, Institute of Water Resources, University of Alaska, College, Alaska, personal communications.

75. Olson, Otmar O., "Aerated Lagoon System for Harvey, North Dakota," Official Bulletin, North Dakota Water and Sewage Works Conference, 33, No. 7-8 (January-February 1966).

76. O'Connor, Donald J, and Eckenfelder, W. Wesley, "Treatment of Organic Wastes in Aerated Lagoons," Journal Water Pollution Control Federation, 32, No. 4, pp 365-382 (April 1960).

77. Oswald, W.J., "Advances in Anaerobic Pond System Design," Advances in Water Quality Improvement, Water Resources Symposium I, University of Texas Press (1968).

78. Oswald, W.S., Lecture notes, Dept. of Civil Engineering, University of California, Berkeley, California (1964).

79. Oswald, William J., and Gotaas, Harold B., "Photosynthesis in Sewage Treatment," American Society of Civil Engineering Transactions, Paper No. 2849, pp 73-97.

80. Pipes, Wesley O., Professor, Dept. of Civil Engineering, Northwestern University, Evanston, Illinois, personal communications (April 8, 1970).

81. Pipes, Wesley O., "Types of Activated Sludge Which Separate Poorly," Journal Water Pollution Control Federation, 41, No. 5, Part 1, pp 714-724 (May 1969).

82. Pipes, Wesley O., Jr., "Basic Biology of Stabilization Ponds," Water and Sewage Works, pp 131-136 (April 1961).

83. Pohl, Edward F., "A Rational Approach to the Design of Aerated Lagoons," Alaska District, U.S. Army Corps of Engineers, Anchorage, Alaska (April 1967).

84. Pohl, E.F., "The Effect of Low Temperatures on Aerobic Waste Treatment Processes," M.S. thesis, University of Washington, Seattle, Washington (1967).

85. Porges, Ralph, and Mackenthun, Kenneth M., "Waste Stabilization Ponds: Use, Function, and Biota," Biotechnology and Bio-Engineering, 5, pp 255-273 (1963).

86. Reed, Sherwood C., and Murphy, R. Sage, "Low Temperature Activated Sludge Settling," Journal of the Sanitary Engineering Division, Proceedings of American Society Civil Engineers, 95, No. SA4 (August 1969).

87. Reid, Leroy C., Jr. "Design and Operation Consideration for Aerated Lagoons in the Arctic and sub-Arctic," Report No. 102, Environmental Engineering Section, Arctic Health Research Center, Environmental

Control Administration, Public Health Service, U.S. Department of Health, Education, and Welfare, College, Alaska (November 1968).

88. Reid, Leroy C., Jr., "The Aerated Sewage Lagoon in Arctic Alaska," presented at the 7th Annual Convention Western Canada Water and Sewage Conference, Edmonton, Alberta, Canada (September 17, 1965).

89. Reid, Leroy C., Jr. and Benson, Barrett E., "Aerated Sewage Lagoons in Arctic Alaska," presented at the 18th Annual Convention of Western Canada Water and Sewage Conference, Regina, Saskatchewan (September 15, 1966).

90. Roguski, Eugene, Biologist, Alaska Dept. Fish and Game, Fairbanks, Alaska, personal communications.

91. Ruble, John and Gray, Danny R., "Stabilization Pond Operation," unpublished report, Eielson Air Force Base, Alaska (1965).

92. Rupke, J.W.G., "Report on the Application of Aerohydraulic Guns to Biological Waste Treatment Systems in the Province of Ontario," Div. of Research, Ontario Water Resources Commission, Publication No. 33, (June 1968).

93. Ryder, Robert A., "Dissolved Oxygen Control in Activated Sludge," presented at the 24th Purdue Industrial Waste Conference, West Lafayette, Indiana (May 7, 1969).

94. Sawyer, Claire N., "New Concepts in Aerated Lagoon Design and Operation," Advances in Water Quality Improvement, Water Resources Symposium I, University of Texas Press (1968).

95. Schmidtke, N.W., "Low Cost Pollution Control With a Ditch-Oriented Modified Brush Aeration System," presented at the 1st Annual Symposium on Water Pollution Research, University of Waterloo, Waterloo, Ontario (January 27, 1966).

96. Schmidtke, N.W., "Low Temperature Oxidation Ditch Field Study," thesis submitted to Dept. of Civil Engineering, University of Alberta, Edmonton, Alberta (April 1967).

97. Slechta, Alfred, Development Engineer, Neptune Microfloc, Inc., Corvallis, Oregon, personal communications (August 13, 1969).

98. Slechta, Alfred S., "High-Rate Processes in Advanced Wastewater Treatment," presented at the 1969 Water Pollution Control Association of Pennsylvania meeting (1969).

99. Smith, Arnold R., "Testing and Rating Surface Aerators," presented at the 11th Ontario Industrial Waste Conference (June 21-24, 1964).

100. Sparling, A.B., "Winter Operation of Sewage Lagoons in Manitoba," Dept. of Health, Section of Environmental Sanitation.

101. Stewart, E., Plant Engineer, Public Works and Engineering Dept., City of Regina, Saskatchewan.

102. Stewart, Mervin J., "Activated Sludge Process Variations - The Complete Spectrum, Water and Sewage Works, pp R2-41-R262 (December 1964).

103. Svore, Germone H., "Waste Stabilization Pond Practices in the United States," Advances in Water Quality Improvement, Water Resources Symposium I, University of Texas Press (1968).

104. Thimsen, D.J., "Biological Treatment in Aerated Lagoons," Minnesota Dept. of Health, 12th Annual Waste Engineering Conference, University of Minnesota (December 1965).

105. Townsend, Allan R., Unsal, Sebre, and Boyko, Boris L., "Aerated Lagoon Design Methods: An Evaluation Based on Ontario Field Data," presented at Purdue Industrial Waste Conference (1969).

106. Upadhyay, J., and Stokes, J.L., "Anaerobic Growth of Psychrophillic Bacteria," Journal of Bacteriology, 83, pp 270-275 (1962).

107. Van Heuvelen, W., Chief Environmental Health and Engineering Services, State Dept. Health, Bismarck, North Dakota, personal communications (February 6, 1969).

108. Walters, Charles F., "Arctic Sewage Lagoons," Proceedings of Symposium on Waste Stabilization Lagoons, Kansas City, Missouri (August 1-5, 1960).

109. Williamson, Arthur E., Mariais, G.R., Shaw, V.A., Eckenfelder, W.W., O'Connor, D.J., and McKinney, R.E., "Summary Report on Stabilization Ponds and Aerated Lagoons," prepared for Missouri Basin Engineering Health Council.

110. Wilson, Walter R., "Design Criteria for a Sewage Oxidation Pond in Arctic Alaska," Report No. AAL-TDR-64-19, Arctic Aeromedical Lab., Arctic Health Research Center, U.S. Public Health Service (February 1965).

111. Wuhrmann, K., Federal Institute of Water Supply, Swiss Federal Institute of Technology, Zurich Switzerland, private communications (March 1, 1967).

112. Wuhrmann, K., "Factors Affecting Efficiency and Solids Production in the Activated Sludge Process," Biological Treatment of Sewage and Industrial Wastes, 1, Edited by B.J. McCabe and W.W. Eckenfelder, Reinhold Publishing Co., N.Y., N.Y. (1956).

SECTION VIII

APPENDIX

FIGURE I
BOD REMOVAL vs DETENTION TIME
Feed: Raw Domestic Sewage, BOD 250 mg/l
Feed Temp: 20°C
Hinde Tubing Diffusers & Open Disc Diffusers

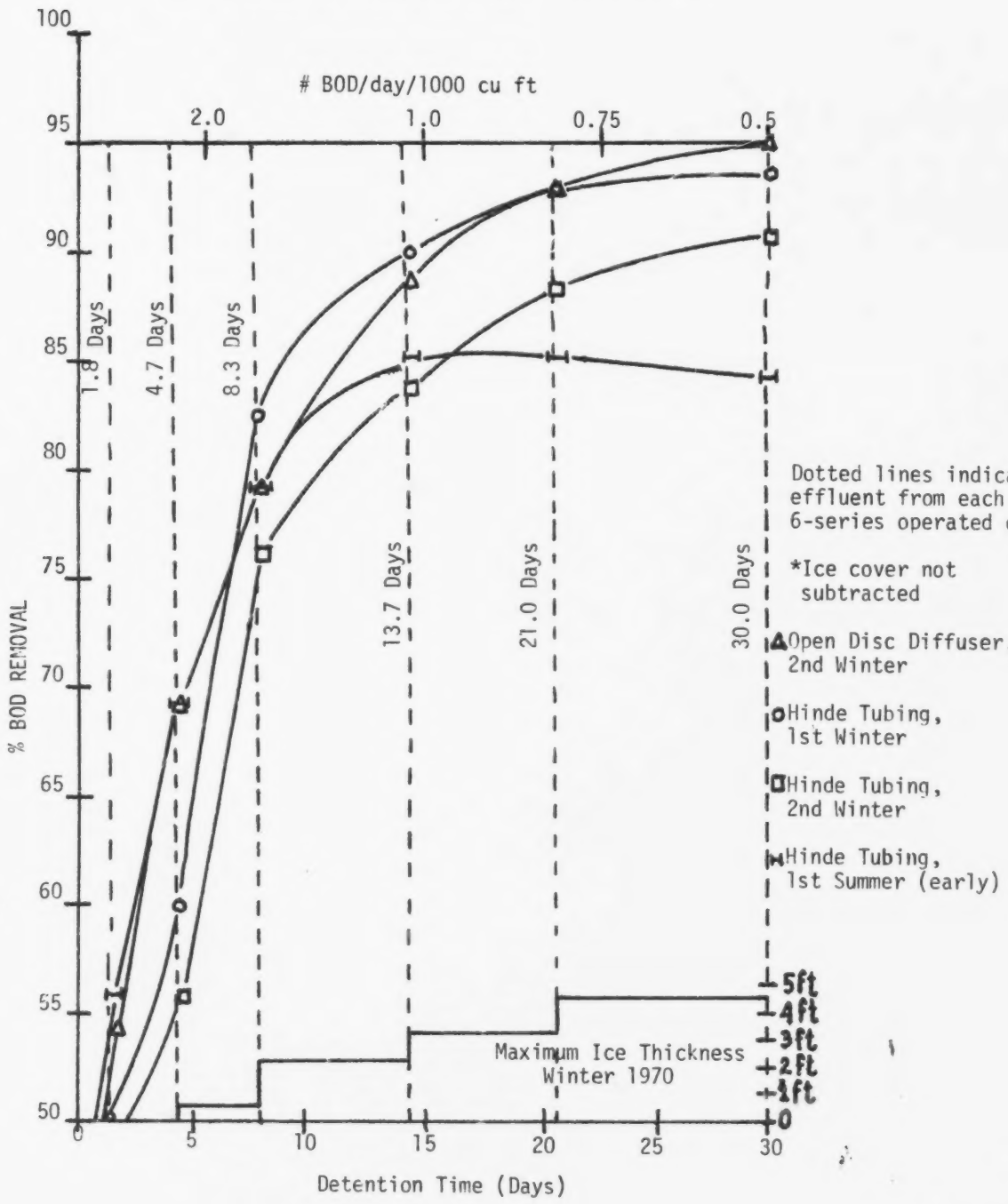


FIGURE 2

NORTHWAY, ALASKA AERATED LAGOON

SLUDGE SAMPLES

June 1967

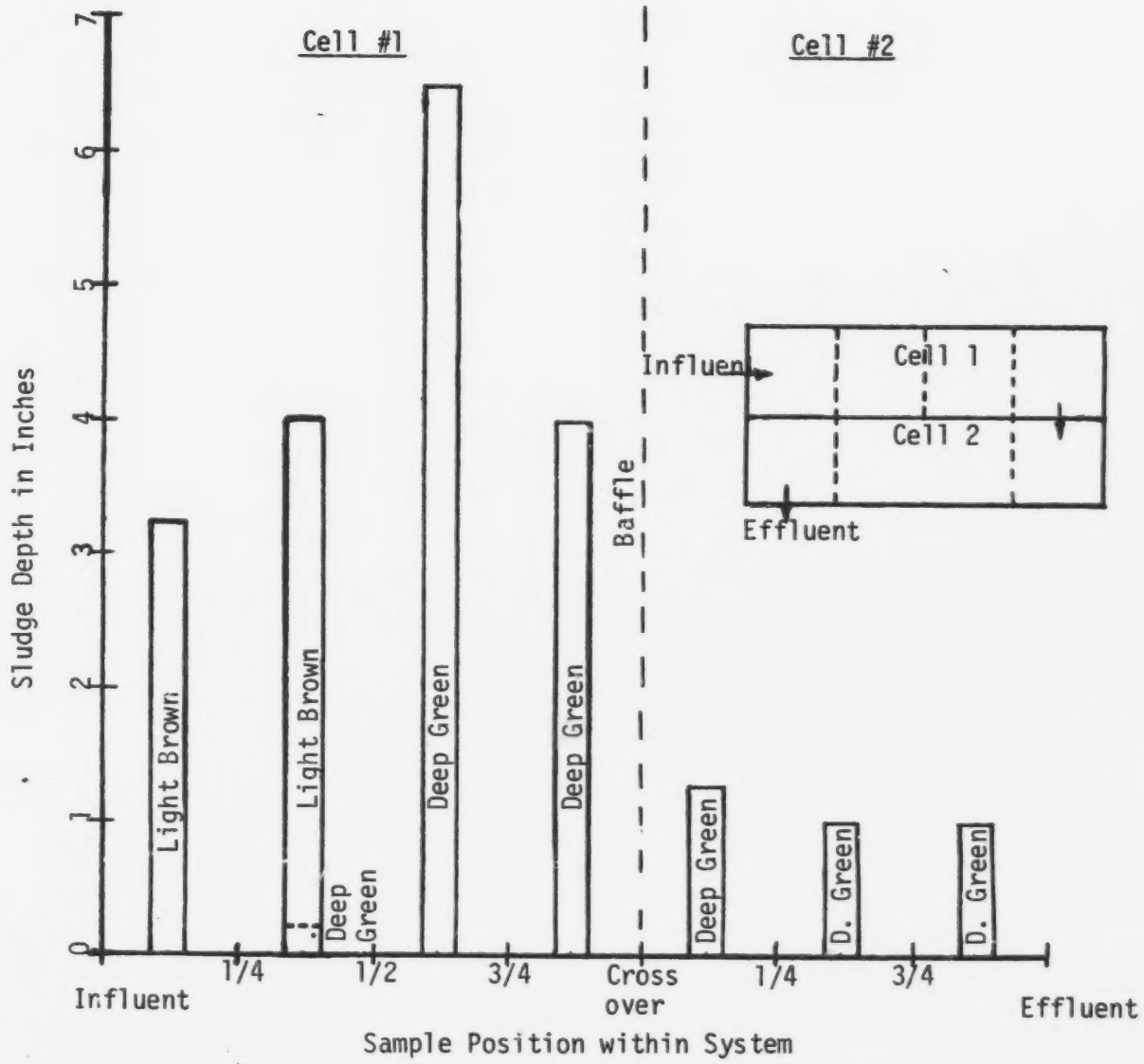
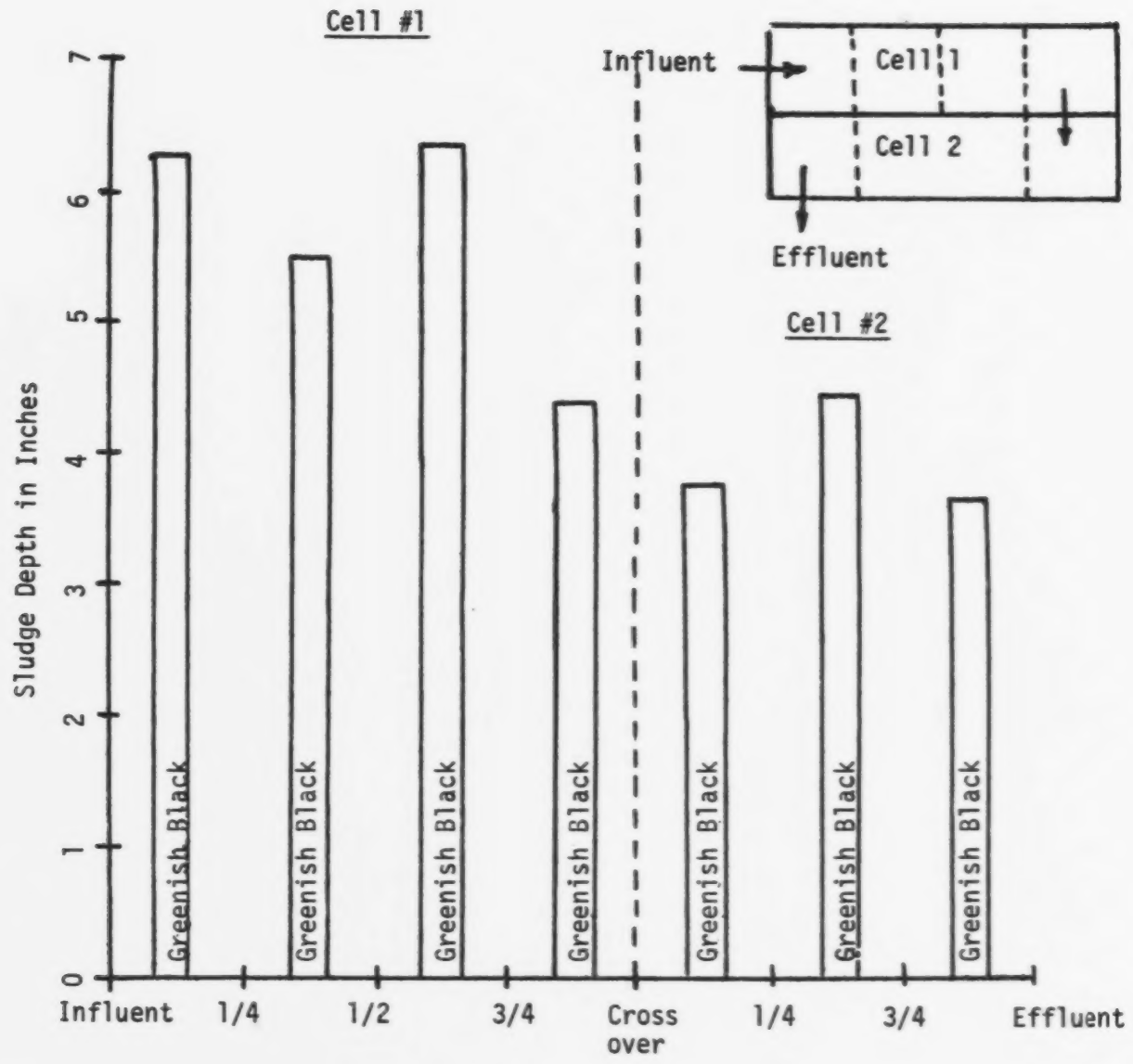


FIGURE 3

NORTHWAY, ALASKA, AERATED LAGOON

SLUDGE SAMPLES

March 1970



Sample Position Within System

TABLE I. NORTHERN REGIONS SEWAGE LAGOON PERFORMANCE STATI

(Compiled From Reports and Publications Referenced in Last Line)[1]

	Inuvik, N.W. Territories	Yellowknife, N.W. Territories before modification	Yellowknife, N.W. Territories After Modification — Series Operation: Primary Cell	Yellowknife, N.W. Territories After Modification — Series Operation: Secondary Cell	Lacombe, Alberta (3140)	Drayton Valley, Alberta (3550) — Series Operation (Cell #2 out 12/20/61-4/11/62): Cell#1	Drayton Valley, Alberta (3550) — Series Operation (Cell #2 out 12/20/61-4/11/62): Cell #2	Drayton Valley, Alberta (3550) — Series Operation (Cell #2 out 12/20/61-4/11/62): Cell #3
Latitude, °N	68°21'	62°	62°	62°	52°	52°	52°	52°
January Average Air Temperature, °F	-28.2 (Febr. -34.1)	-20.3 (Febr. -28.2)	-20.3	-20.3	Edmonton +3.7	Edmonton +3.7	Edmonton +3.7	Edmonton +3.7
Lagoon Type	Facultative	Facultative	Anaerobic	Facultative	Facultative	Facultative	Facultative	Facultative
Lagoon Depth (ft.)	1.9-3.4	3.2	8.0	3.2	5.0	5.0	5.0	4.0
Detention Time (days)	73-136	134	0.6	99	202	52	33	36
Loading--#BOD_5/acre/day --#BOD_5/1000 ft.^{3}/day	8.9-9.6 0.082	35 0.108	5170-6170 11.9-14.2	18.8-19.4 0.136	25.7 0.118	55.5 0.255	Summer/Winter 26.9/62.0 0.124/0.285	Summer/Winter 9.2/ 38.6 0.05/0.222
Ice Conditions--Duration (Starting Month to End Month) --Depth (ft.)	October May To bottom except at inlet	October May 1-1/2	None 0	October May 1-1/2	November March 5.0	November April 2.0	November April 2.5	November April 2.5
Sewage--Source --Winter Temperature, °C	Raw Domestic 19°C	Raw Domestic <6.5°C	Raw Domestic <6.5°C	Primary Effluent <1.5°C	Raw Domestic 9-10°C	Raw Domestic --	Primary Effluent <1.0°C	Cell #2 Effluent <0.5°C
Lagoon Temperature--Summer, °C --Winter, °C	12.5-20°C <1°C	14-20°C 1°C	14-20°C 1°C	14-20°C <1°C	18°C <1°C	19-21°C 0.5-3°C	19-23°C 0.5-3°C	19-21°C 0.5-3°C
Operation Efficiency --BOD, Summer % Removed --BOD, Winter % Removed	73-89 41	70 41	36 36	75* (61)** 59 (35.9)	92.0 30.1	70.5 29.1	86.0* (52.5)** 40.8 (16.5)	92.5* (46.4) 53.5 (21.4)
--Suspended Solids, Summer, % Removed --Suspended Solids, Winter, % Removed	92 85	-- --	-- --	-- --	7/ 68	61.1 69.2	56.6 (-11.5) 71.7 (8.1)	58.1 (3.4) 72.7 (3.5)
--Total Coliforms, Summer, % Removed --Total Coliforms, Winter, % Removed	99.7 99.9+	-- --	73 80	99.99 97.7	-- --	-- --	-- --	-- --
Odor Conditions Near Lagoons	Noticeable at 700 ft.	Definite Problem	None Reported	None Reported	Low Level	Low Level	Low Level	Low Level
Comments	Swamp area with brush and trees in lagoon	Nearly anaerobic with some exposed sludge banks	--	Natural lake with construction deficiencies	--	--	--	--
Bottom Sludge Accumulation, ft.^{3}/1000 capita/day	--	--	12.9	--	--	--	--	--
Information and Data Source Reference	Dawson, 1967	Dawson, 1967	Dawson, 1967		Higo, 1965	Higo, 1965		

[1]This table should be interpreted as a partial listing. *Total system efficiency at any stage **Removal efficiency of individual ce

	Sutherland (Saskatoon), Saskatchewan — Series Operation #1	Sutherland (Saskatoon), Saskatchewan — Series Operation #2	Portage LaPrairie, Manitoba	Fort Yukon, Alaska (School)	Lazy Mountain Children's Home, Palmer, Alaska	Camrose, Alberta (7708) — Series Operation: Primary #1	Camrose, Alberta (7708) — Series Operation: Primary #2	Camrose, Alberta (7708) — Series Operation: Secondary #1
Latitude, °N	52°	52°	52°	Arctic Circle	62°	52°	52°	52°
January Average Air Temperature, °F	-1	-1	--	-12	+12	Edmonton +3.7	Edmonton +3.7	Edmonton +3.7
Lagoon Type	Anaerobic	Anaerobic	Facultative	Facultative	Facultative	Anaerobic	Facultative	Facultative
Lagoon Depth (ft.)	17	17	--	3.0	2-5	10.0	10.0	5.0
Detention Time (days)	2.75-1.45	2.75-1.45	--	--	2+	6.2	5.75	3.45
Loading--#BOD_5/acre/day --#BOD_5/1000 ft.^{3}/day	1300-2600 3.5-7.0	-- --	30-80 --	85 (winter only) 0.75	40 0.46	Summer/Winter 808/808 3.71/3.71	Summer/Winter 488/514 2.24/2.36	Summer/Winter 697/754 3.20/3.46
Ice Conditions--Duration (Starting Month to End Month) --Depth (ft.)	None --	-- Periodic thin sheets	November April --	-- To bottom at edges	October April 2	November March Nil-0.3	November March Nil-1.0	November March 2.5
Sewage--Source --Winter Temperature, °C	Raw Domestic 10-14°C	Cell #1 --	-- --	School 20°C	School --	Raw Domestic + Milk Process. 14-16°C	Primary #1 Effluent 1-5°C	Primary #2 Effluent 1-4°C
Lagoon Temperature--Summer, °C --Winter, °C	-- 5-7.8°C	-- 2.8-4.5°C	-- --	-- <1.0°C	-- 1.5°C	17-23°C 1-5°C	17-23°C 1-4°C	17-23°C 0.5-3°C
Operation Efficiency --BOD, Summer % Removed --BOD, Winter % Removed	-- --	30-50 20-35	85-98 36	-- --	-- 35-50	44.5 41.2	55.1* (19.1)** 46.6 (9.2)	59.4* (9.6)** 52.4 (10.9)
--Suspended Solids, Summer, % Removed --Suspended Solids, Winter, % Removed	-- --	55-70 55-70	-- --	-- --	-- --	52.8 79.6	56.9 (8.7) 85.8 (30.4)	73.8 (39) 87.1 (9.2)
--Total Coliforms, Summer, % Removed --Total Coliforms, Winter, % Removed	-- --	80-90 70-80	-- --	-- --	-- --	-- --	-- --	-- --
Odor Conditions Near Lagoons	Detectable at Less than 300'	Detectable at Less than 300'	None Reported	None Noticed	2 weeks in Spring	Moderate to High	Moderate to High	Slight
Comments	Noticed efficiency reduction w/length of service	Odors seem to be coming from floating grease,scum	Two ponds operated alternately	No overflow High groundwater area	--	School Load Plus Milk Processing Plant Sludge--thick, black Offensive odor to good draining fine dark		
Bottom Sludge Accumulation, ft.^{3}/1000 capita/day	14.0	--	--	--	--	9.5-10.1	9.5-10.1	--
Information and Data Source Reference	Brisbin, 1967		Sparling, 1961	Anderegg, 1960	Anderegg, 1959	Higo, 1965		

S SEWAGE LAGOON PERFORMANCE STATISTICS

n Reports and Publications Referenced in Last Line)[1]

	Lacombe, Alberta (3140)	Drayton Valley, Alberta (3550) Series Operation (Cell #2 out 12/20/61-4/11/62) Cell#1	Cell #2	Cell #3	Stettler, Alberta (3800) Operated in Series Primary #1	Primary #2	Secondary #1	Secondary #2	Norman Wells, N.W. Territories
	52°	52°	52°	52°	52°	52°	52°	52°	65°
	Edmonton +3.7	Edmonton +3.7	Edmonton +3.7	Edmonton +3.7	Edmonton +3.7	Edmonton +3.7	Edmonton +3.7	Edmonton +3.7	--
	Facultative	Facultative	Facultative	Facultative	Anaerobic to Facultative	Facultative	Facultative	Facultative	Anaerobic
	5.0	5.0	5.0	4.0	10	5	5	5	2
	202	52	33	36	5.94	6.20	75.2	87.4	23
	25.7 0.118	55.5 0.255	Summer/Winter 26.9/62.0 0.124/0.285	Summer/Winter 9.2/ 38.6 0.05/0.222	1433 3.29	Summer/Winter 488 / 429 2.24 / 1.97	Summer/Winter 20.8 / 35.8 0.096 / 0.164	Summer/Winter 3.49 / 24.2 0.016 / 0.11	49 0.56
	November March 5.0	November April 2.0	November April 2.5	November April 2.5	December February Short durations 0.3	December March 0.2-1.0	November April 3.5	November April 3.5	-- --
nt	Raw Domestic 9-10°C	Raw Domestic --	Primary Effluent <1.0°C	Cell #2 Effluent <0.5°C	Raw Domestic + Milk Process. 8-11°C	Cell #1 Effluent 1.5-5°C	Cell #2 Effluent 0.5-3°C	Cell #3 Effluent 0.2-2°C	Airport --
	18°C <1°C	19-21°C 0.5-3°C	19-23°C 0.5-3°C	19-21°C 0.5-3°C	18-22°C 1.5-5°C	17-21°C 0.5-3°C	18-22°C 0.2-2°C	18-22°C 0.1-1°C	-- --
	92.0 30.1 76 68 -- --	70.5 29.1 61.1 69.2 -- --	86.0* (52.5)** 40.8 (16.5) 56.6 (-11.5) 71.7 (8.1) -- --	92.5* (46.4)** 53.5 (21.4) 58.1 (3.4) 72.7 (3.5) -- --	37.0 28.2 69.6 64.1 -- --	63.6* (42.3)** 37.3 (12.7) 71.1 (4.9) 74.1 (27.9) -- --	93.0* (F0.7)** 51.1 (22.0) 74.5 (11.8) 85.2 (42.6) -- --	95.5* (35.7)** 73.0 (44.6) 87.1 (49) 87.1 (12.8) -- --	-- 67 -- -- -- --
	Low Level	Low Level	Low Level	Low Level	Moderate	Moderate	Nil	Nil	None Reported
es	--	--	--	--	Algae showed in this pond from April to fall	--	Storage with release spring and fall	Storage with release spring and fall	--
	--	--	--	--	8.75	--	--	--	--
	Higo, 1965	Higo, 1965			Higo, 1965				Dawson, 1965

fficiency at any stage **Removal efficiency of individual cell considering only the load that particular cell receives

	Lazy Mountain Children's Home, Palmer, Alaska	Camrose, Alberta (7708) Series Operation Primary #1	Primary #2	Secondary #1	Secondary #2	Long Detention #1	Long Detention #2	Eielson AFB Experimental System (Fairbanks, Ak.
	62°	52°	52°	52°	52°	52°	52°	64°
	+12	Edmonton +3.7	Edmonton +3.7	Edmonton +3.7	Edmonton +3.7	Edmonton +3.7	Edmonton +3.7	-10
	Facultative	Anaerobic	Facultative	Facultative	Facultative	Facultative	Facultative	Facultative
	2-5	10.0	10.0	5.0	5.0	5.0	5.0	4.5
	2+	6.2	5.75	3.45	3.45	101	93	18
	40 0.46	Summer/Winter 808/808 3.71/3.71	Summer/Winter 488/514 2.24/2.36	Summer/Winter 697/754 3.20/3.46	Summer/Winter 590/693 2.71/3.18	Summer/Winter 135/23.4 0.062/0.107	Summer/Winter 2.1/21.6 0.01/0.10	125 0.637
	October April 2	November March Nil-0.3	November March Nil-1.0	November March 2.5	November April 3.0	November April 3.0	November April 3.0	November April <1.0
	School --	Raw Domestic + Milk Process. 14-16°C	Primary #1 Effluent 1-5°C	Primary #2 Effluent 1-4°C	Secondary #1 Effluent 0.5-3°C	Secondary #2 Effluent 0.5-3°C	Long Det. #1 Effluent 0.1-2°C	Air Base Domestic 21°C
	-- 1.5°C	17-23°C 1-5°C	17-23°C 1-4°C	17-23°C 0.5-3°C	18-23°C 0.5-3°C	19-23°C 0.1-2°C	19-23°C 0.1-3°C	19-21°C 1°C
	-- 35-50 -- -- -- --	44.5 41.2 52.8 79.6 -- --	55.1* (19.1)** 46.6 (9.2) 56.9 (8.7) 85.8 (30.4) -- --	59.4* (9.6)** 52.4 (10.9) 73.8 (39) 87.1 (9.2) -- --	77.6* (44.7)** 52.8 (0.8) 79.0 (19.8) 91.0 (30.2) -- --	96.3* (83.5)** 60.3 (15.9) 77.7 (-6.2) 91.8 (8.9) -- --	49* (98.1)** 71.5 (28.2) 92.7 (67.3) 93.6 (21.8) -- --	73 51 87 87 -- --
	2 weeks in Spring	Moderate to High	Moderate to High	Slight	Slight	Not Noticeable	Not Noticeable	None Reported
	--	School Load Plus Milk Processing Plant Sludge--thick, black Offensive odor to good draining fine dark						Bottom sludge taken in Jan. & Febr. had 50% volatiles
	--	9.5-10.1	9.5-10.1	--	--	--	--	--
	Anderegg, 1959	Higo, 1965						Rubel, 1965

TABLE 2

RED DEER, ALBERTA SEWAGE LAGOON SYSTEM CHARACTERISTICS

(Reported by T.T. Higo, 58)

Population: 23,000
Feed: Domestic sewage plus industrial wastes from milk processing, brewery, poultry processing, and meat packing.
Average BOD_5: 350 mg/l; Average Suspended Solids: 400 mg/l

Unit	Detention Time/ Days	BOD Load #/1000 ft^3/day Summer	Winter	Summer BOD Removal % Per Unit	Accum.	Winter BOD Removal % Per Unit	Accum.	Winter Susp. Solids Removal % Per Unit	Accum.
All 5 cells operating in series, Fall 1961 to July 1963									
1	3.38	8.03	8.03	46.8	46.8	27.8	27.8	63.4	63.4
2	3.38	4.30	5.80	18.5	56.5	25.1	45.8	35.3	76.2
3	3.38	3.48	4.33	18.0	64.4	11.0	51.7	27.9	82.8
4	3.38	2.85	3.86	17.4	71.5	Increase	-	0	82.8
5	3.38	2.36	4.08	14.8	75.0	5.4	52.0	17.5	86.0
Cell #1 taken out of operation after July 1963									
2	2.03	10.8	10.8	48.4	48.4	38.1	38.1	56.4	56.4
3	2.03	5.56	6.58	2.7	49.8	21.4	52.1	42.6	74.8
4	2.03	5.42	5.15	36.6	68.1	15.4	59.4	35.4	83.9
5	2.03	3.43	4.36	17.0	73.6	9.8	63.4	0	83.9

SLUDGE ACCUMULATION RATE

Location	Survey Period	Accum.Rate Ft^3/day/ 1000 Persons
Pond #1	6/62	13.5
	6/62-10/62	3.15
	10/62- 6/63	9.40
	6/62- 6/63	7.21
Pond #2	7/64	2.38

SLUDGE TEMPERATURE, POND #1

10/23/62	9°C	3/12/64	11.5°C
2/13/63	9°	4/16/64	12 °
6/19/63	13°	5/ 6/64	12.7°
9/19/63	13°	6/17/64	18 °
		7/ 7/64	21 °

TABLE 3

EXISTING LAGOON DESIGN CRITERIA

(FACULTATIVE LAGOONS)

State or Province (Agency)	Loading Rate #BOD/ Acre/Day	Persons/ Acre/Day	Depth In Feet	Detention Time In Days	Storage Requirements Days
Alaska	20	100	-	60	-
Alberta					
No stream for dilution	-	-	Max. 5 Min. 2	365	365
To receiving stream	-	-	Max. 5 Min. 3	Primary 14 Secondary 90	- -
Colorado	21.78	100	-	-	-
Manitoba	40-50	200-250	Max. 4 Depth Adjustment between 1 & 4	-	As required 60-120 days Nov 1-May 31
Minnesota	21.78	100	Max. 5 Min. 2	-	-
Montana	18-20	-	-	-	-
North Dakota	-	100	Max. 5 Min. 3	-	-
Ontario Water Resources Commission	20	100	Max. 5 Min. 2	-	Winter storage recommended for severe climatic conditions
South Dakota	21.78	100	Max. 5 Min. 2	-	-

TABLE 4

SLUDGE BULKING HYPOTHESES

(Presented by Wesley O. Pipes, 81)

1. Any type of activated sludge can be lost into the effluent if the secondary settling tank is designed inadequately or operated poorly.

2. There are several different types of activated sludge which are difficult to separate from the effluent even with a well designed and well operated sedimentation tank.

3. The production of each specific type of sludge which separates poorly is caused by some specific deficienty in the composition of the waste or in one of the environments in the process.

4. Non-filamentous bulking sludge occurs when the activated sludge organisms secrete an extracellular material with a high degree of hydration producing a sludge with excessive amounts of bound water.

5. Chlorination of a non-filamentous bulking sludge will decrease the SVI rapidly (in a matter of minutes) because of a plysical change in the state of hydration in the sludge particle's extracellular material.

6. Bulking sludge can be produced by excessive growths of fungi in the sludge.

7. A pH less than 5 in the aeration tank can result in the growth of large masses of various fungi in the sludge. This is not bulking but a form of deflocculation.

8. The fungi which produce bulking sludge are those which can grow as single cells (blastospores or arthrospores) as well as in the filamentous form.

9. Bulking sludge produced by an excessive growth of fungus never has an SVI of over 300 ml/g.

10. Bulking sludge can be produced by the excessive growth of any one of a number of different filamentous bacteria including members of the genera Bacillus, Sphaerotilus, Beggiatoa, Thiothrix, Nocardia and others.

11. The SVI of a bulking sludge can be changed rapidly by manipulation of the physical and chemical environment. However, the SVI of normal sludge changes only slowly by population replacement mechanism.

12. The particular environmental factors which can be manipulated to change the SVI of a filamentous bulking sludge depend on the specific organism which produces the bulking.

TABLE 4 Continued

13. The growth of a specific filamentous organism in activated sludge depends on establishment of particular conditions which are different for the various types of filamentous organisms which can produce bulking.

14. The gases produced in activated sludge which goes anaerobic in the absence of nitrates are H_2S and fermentation products such as CO_2, H_2, etc.

15. Floating sludge can be produced by the accumulation of large numbers of dead stalked ciliates in the sludge.

16. Floating sludge can be produced by the excessive growth of predatory fungi (Arthrobotrys and related genera) feed on nematodes in the sludge.

17. Floating sludge can be produced by the excessive growth of predatory fungi (Zoophagus and related genera) feeding on rotifers in the sludge.

18. Floating sludge can be produced by the excessive growth of saprophytic fungi in the sludge.

BIBLIOGRAPHIC:
Biological Waste Treatment in the Far North. Clark, Sidney E., Alaska Water Laboratory, FWQA

ABSTRACT:
A literature review has been conducted to establish the published state-of-the-art of biological waste treatment for cold regions applications. Operating agencies throughout the cold regions of the Northern Hemisphere, but particularly in the northern United States and Canada, have provided discussion of their experience and have offered recommendations through letters and other forms of personal communication. The review centers on the feasibility for cold regions application of lagoons (aerated, facultative and anerobic) and extended aeration (12 to 36 hours detention activated sludge) with emphasis placed on the effectiveness of processes at low temperatures while treating domestic sewage. Although definite design criteria are not established, many of the recommendations and conclusions should provide a better basis for cold regions design of biological waste treatment facilities. The limitations of existing knowledge are expressed and recommendations for continued research are presented.

ACCESSION NO.

KEY WORDS:
Arctic Sewage Treatment
Biological Waste Treatment
Low Temperature Biological Treatment
Waste Treatment
Sewage Treatment
Arctic Sewage Treatment
Cold Regions Extended Aeration
Low Temperature Activated Sludge

BIBLIOGRAPHIC:
Biological Waste Treatment in the Far North. Clark, Sidney E., Alaska Water Laboratory, FWQA

ABSTRACT:
A literature review has been conducted to establish the published state-of-the-art of biological waste treatment for cold regions applications. Operating agencies throughout the cold regions of the Northern Hemisphere, but particularly in the northern United States and Canada, have provided discussion of their experience and have offered recommendations through letters and other forms of personal communication. The review centers on the feasibility for cold regions application of lagoons (aerated, facultative and anerobic) and extended aeration (12 to 36 hours detention activated sludge) with emphasis placed on the effectiveness of processes at low temperatures while treating domestic sewage. Although definite design criteria are not established, many of the recommendations and conclusions should provide a better basis for cold regions design of biological waste treatment facilities. The limitations of existing knowledge are expressed and recommendations for continued research are presented.

ACCESSION NO.

KEY WORDS:
Arctic Sewage Treatment
Biological Waste Treatment
Low Temperature Biological Treatment
Waste Treatment
Sewage Treatment
Arctic Sewage Treatment
Cold Regions Extended Aeration
Low Temperature Activated Sludge

BIBLIOGRAPHIC:
Biological Waste Treatment in the Far North. Clark, Sidney E., Alaska Water Laboratory, FWQA

ABSTRACT:
A literature review has been conducted to establish the published state-of-the-art of biological waste treatment for cold regions applications. Operating agencies throughout the cold regions of the Northern Hemisphere, but particularly in the northern United States and Canada, have provided discussion of their experience and have offered recommendations through letters and other forms of personal communication. The review centers on the feasibility for cold regions application of lagoons (aerated, facultative and anerobic) and extended aeration (12 to 36 hours detention activated sludge) with emphasis placed on the effectiveness of processes at low temperatures while treating domestic sewage. Although definite design criteria are not established, many of the recommendations and conclusions should provide a better basis for cold regions design of biological waste treatment facilities. The limitations of existing knowledge are expressed and recommendations for continued research are presented.

ACCESSION NO.

KEY WORDS:
Arctic Sewage Treatment
Biological Waste Treatment
Low Temperature Biological Treatment
Waste Treatment
Sewage Treatment
Arctic Sewage Treatment
Cold Regions Extended Aeration
Low Temperature Activated Sludge

As the Nation's principal conservation agency, the Department of the Interior has basic responsibilities for water, fish, wildlife, mineral, land, park, and recreational resources. Indian and Territorial affairs are other major concerns of America's "Department of Natural Resources."

The Department works to assure the wisest choice in managing all our resources so each will make its full contribution to a better United States—now and in the future.